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THE EFFECT OF ENVIRONMENTAL FACTORS ON THE RESPIRATORY HEALTH OF SCHOOL CHILDREN IN HAMILTON

CURRENT REPORT #6

October 1, 1981

(Volume 4-2) APPENDICES AND PART 9

URBAN AIR ENVIRONMENT GROUP

McMASTER UNIVERSITY

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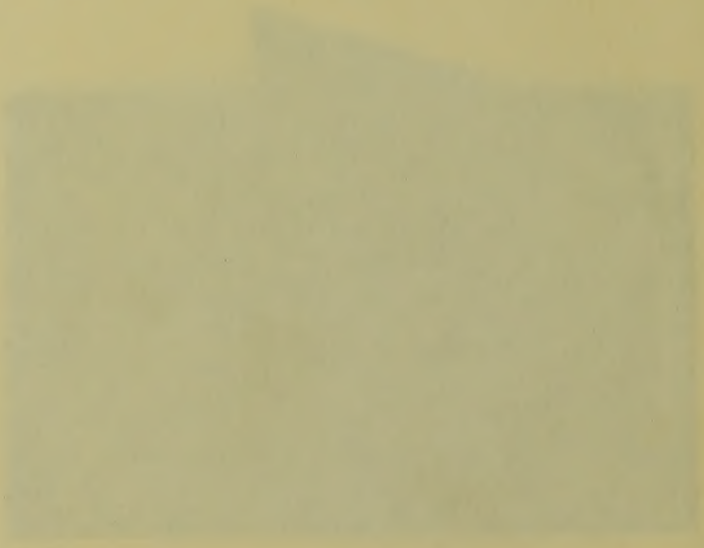
Submitted by:

A. T. Kerigan and L. D. Pengelly
Department of Medicine

C. H. Goldsmith
Department of Clinical Epidemiology and Biostatistics

B. K. Garside
Department of Engineering Physics

McMaster University
Hamilton, Ontario
Canada



PART 9

EXPOSURE ESTIMATION

9.1 OVERVIEW

Our previous reports have described the development of models permitting the exposure to Total Suspended Particulates (TSP) and Sulphur Dioxide (SO_2) to be estimated at a given point within Hamilton. The inputs into this model have been the measurements of TSP and SO_2 from the Air Quality Networks. Underlying this approach is the assumption, implicit in most previous work, that this exposure estimate is applicable to all of a subject's daily activities both indoor and outdoor; however, two factors reduced the validity of this approach. The first factor is the presence of indoor sources of pollutants, in particular cigarette smoking and the use of gas burning devices. We have attempted to allow for this factor so far in the study in a quantitative sense by the use of questionnaire data on smoking and gas burning devices. During the current year, indoor multipollutant samples will be measuring levels of TSP, SO_2 and NO_2 in schools and some homes to allow for semi-quantitation of these indoor sources. (See PART 7 on Indoor Monitoring.)

The second factor reducing the validity of the approach described above is the ability of the indoor and the outdoor environment to equalibrate. With the increasing efficiency of winter-time insulation and house sealing, and the increasing use of central air conditioning in the summer, it can no longer be assumed that the indoor environment follows the outdoor, even though there may be no indoor sources of pollutants. In order to estimate what gradients between the indoor and outdoor environments might exist in a number of situations, the indoor monitoring project has been utilizing outdoor monitors simultaneously. This will give further useful information as to the the relationship between indoor and outdoor levels of pollutants, and as to what factors modify this relationship.

9.2 TIME BUDGETS OF CHILDREN

These indoor measurements will permit better quantitation of the exposure of children to the measure of pollutants in the different environments in which they study, play and sleep. In order to use this information to estimate total exposure of the child to any one pollutant, we need to know what proportion of time the children do spend in each of these different environments (specifically the home, the school, and the outdoors around the school and the home). The proportion will vary with the season of the year, and of course, with

school vacations. To measure these time budgets, questionnaires have been developed. These are shown in Appendix 9-1. During the school year, there is one questionnaire for school days and one questionnaire for the week-end. These questionnaires are completed by the children in the schools, with the pulmonary function technician available for clarification. A questionnaire similar to the week-end questionnaire was used during the summer school vacation in a telephone survey of parents. We have completed the Spring and the Summer vacation surveys; the Fall survey is underway. With the completion of the winter survey between January and February, 1982, we will have good information on the time budgets of the children, which can then be incorporated into estimation of total exposure of children to the pollutants of concern.

APPENDIX 2-1

QUESTIONNAIRE CHILDREN'S EPIDEMIOLOGIC STUDY

1. Do you cough in the morning not counting just clearing your throat?

   1. YES
   2. NO

   ☐

   IF YES, ANSWER Q.2
   IF NO, GO TO Q.3

2. Do you cough like this most mornings for as much as three months in a row each year?

   1. YES
   2. NO

   ☐

3. Do you usually cough during the day or night, not counting just clearing your throat?

   1. YES
   2. NO

   ☐

   IF YES, ANSWER Q. 4
   IF NO, GO TO Q. 5

4. Do you cough like this most days or nights for as much as three months in a row each year?

   1. YES
   2. NO

   ☐

5. Does your chest ever sound wheezy or whistling?

   1. YES
   2. NO

   ☐

6. Have you suffered from an attack of asthma in the last year?

   1. YES
   2. NO

   ☐

7. When you have a cold, does it usually go to your chest?

   1. YES
   2. NO

   ☐

APPENDIX 3-1

APPENDIX 3-1

CARBON MONOXIDE (CO) SUBSTUDY

As of May 1981, one of our Teams of Pulmonary Function testers started measuring CO levels on all the children who were being tested. We used an Energetics Science Inc. Ecolyzer, calibrated twice a day with a known gas mixture of 50 ppm. CO in air. Before the child performed any Pulmonary Function test, he/she was asked to fill a sample bag with expired air after holding his/her breath for 20 seconds. This was immediately sampled by the Ecolyzer. The CO level and the time of day were recorded. We hoped from the information obtained to get some validation of the child's own smoking status, as determined from a questionnaire, and possibly to see an effect of parental smoking.

We were not able to measure as many children as we had hoped before before schools closed for the summer, because of a difficulty in obtaining replacement calibrating gas. However, we established the feasibility of such a study. All the children, except one, were able to perform the test with no problems. The technicians were able to add this test to the existing protocol and to code the information without adversely affecting the number of children who could be tested each day.

82 children were tested. The mean value of CO recorded was 2.67% CoHb (S.D. 1.52.)

We intend to continue this study when we resume testing in September 1981.

APPENDIX 3-2

APPENDIX 3-2

CANADIAN THORACIC SOCIETY

ANNUAL MEETING-SASKATOON JUNE 1981

Poster Session: Single-Breath Nitrogen Washout (NWs) as an Epidemiological Survey Tool in Children.

We compared the NWs with the FVC in terms of practicality, i.e., could the children do the test (Figure 3-2-1). It can be seen that the percentage of children performing successful maneuvers for the NWs was much less than for the FVC. Each child was allowed up to five "tries" to perform two successful maneuvers. When we analyzed a subgroup of 706 children by age and by "try" (Figure 3-2-2) we found that it was the younger children who had the greatest difficulty. We also found that after an initial learning effect, the success rate started to fall after the second "try".

We also compared the NWs with the FVC for the reproducibility of variables obtained from the two tests. Eight children in each school are routinely retested, so that the reproducibility of variables can be assessed. FVC and FEV_1 from the FVC maneuver were much more reproducible than the CV and N_2 difference from the NWs maneuver (Figure 3-2-3). We examined reproducibility in more detail by obtaining six

repeat FVC and NWs maneuvers on a subset of 48 children. We imposed stricter criteria for flow rates for this group. Mean and peak flows were not allowed to exceed 0.3 litres per second and 0.5 litres per second, respectively. We calculated the coefficient of variation for variables from both tests. Again we found that the reproducibility of all variables from the FVC was better than that of those from the NWs (Figure 3-2-4).

Our conclusion was that the NWs was greatly inferior to the FVC as an epidemiological survey tool in children. As a result of these investigations, we had stopped using this test as of the end of Year 2.

Figure 3-2-1

SUCCESS RATE

NWs / FVC

% children performing successful manœuvre

YEAR 1

1st 4 schools	last 4 schools
n=514	n=166

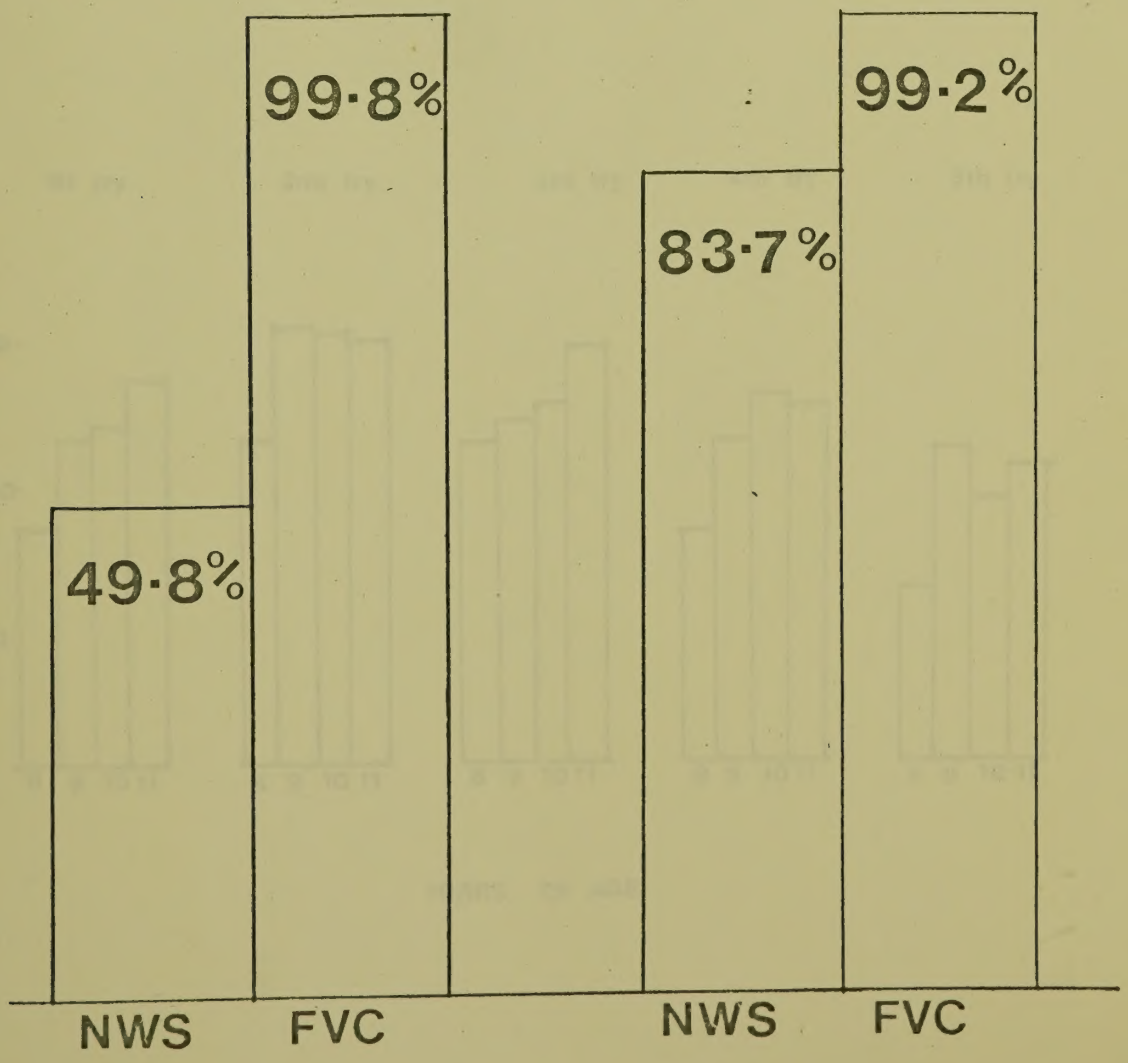
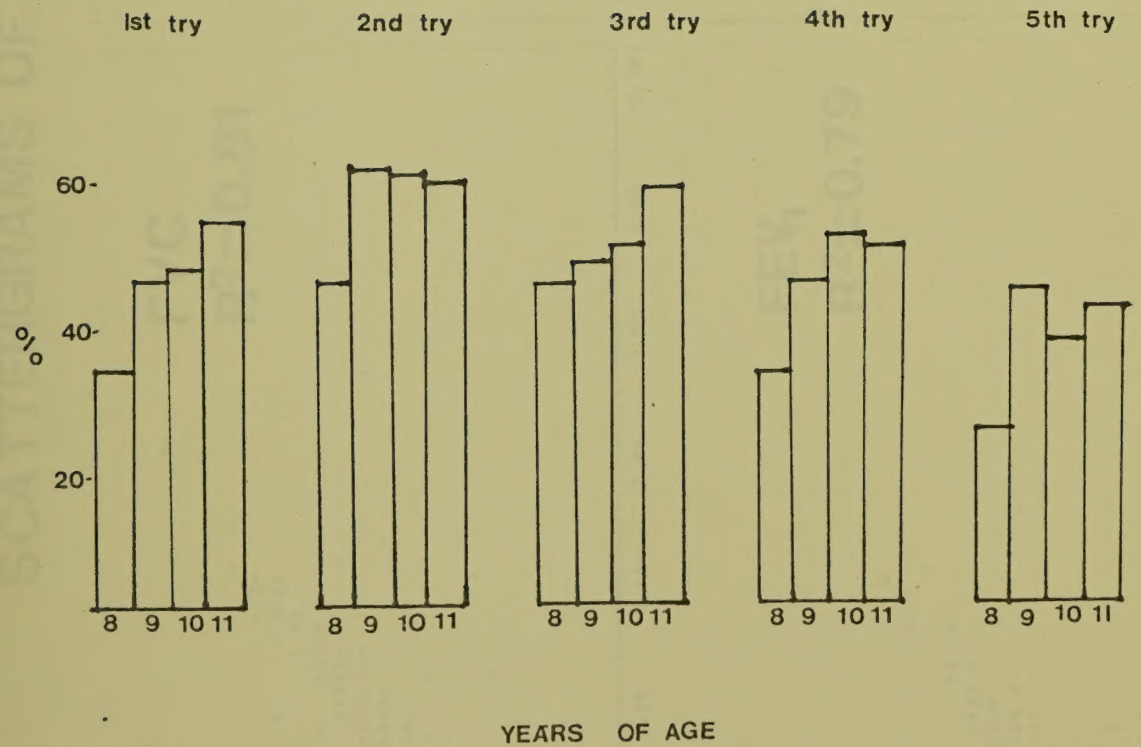


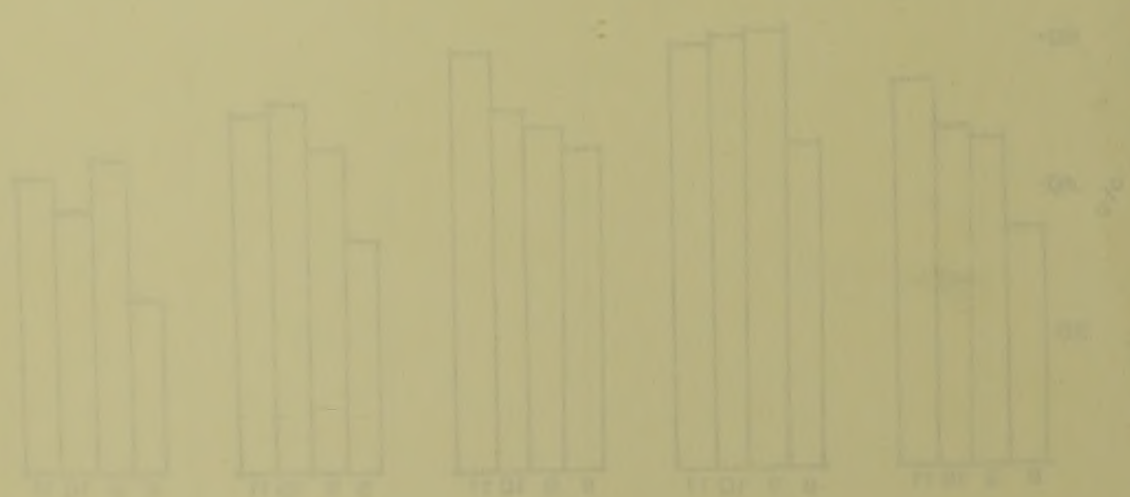
Figure 3-2-2

SUCCESS RATE BY TRY - BY AGE

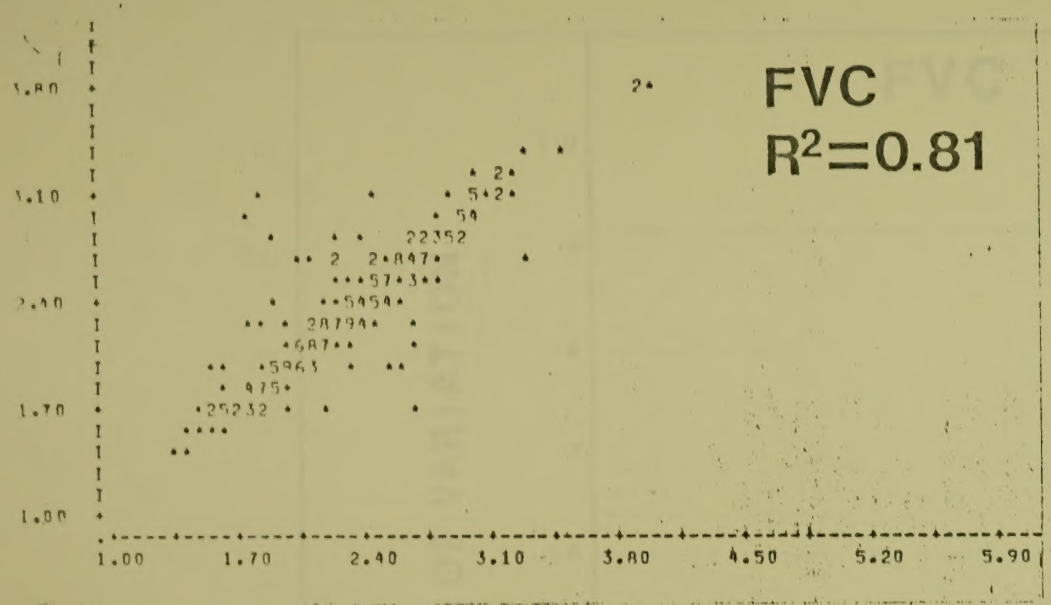
%o children performing successful manoeuvre

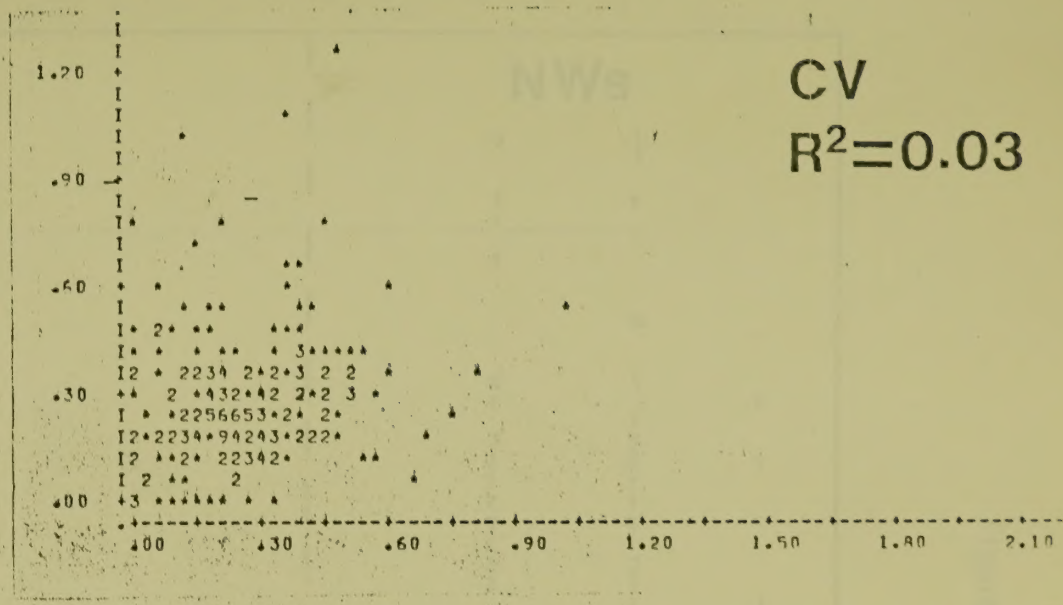
n = 706

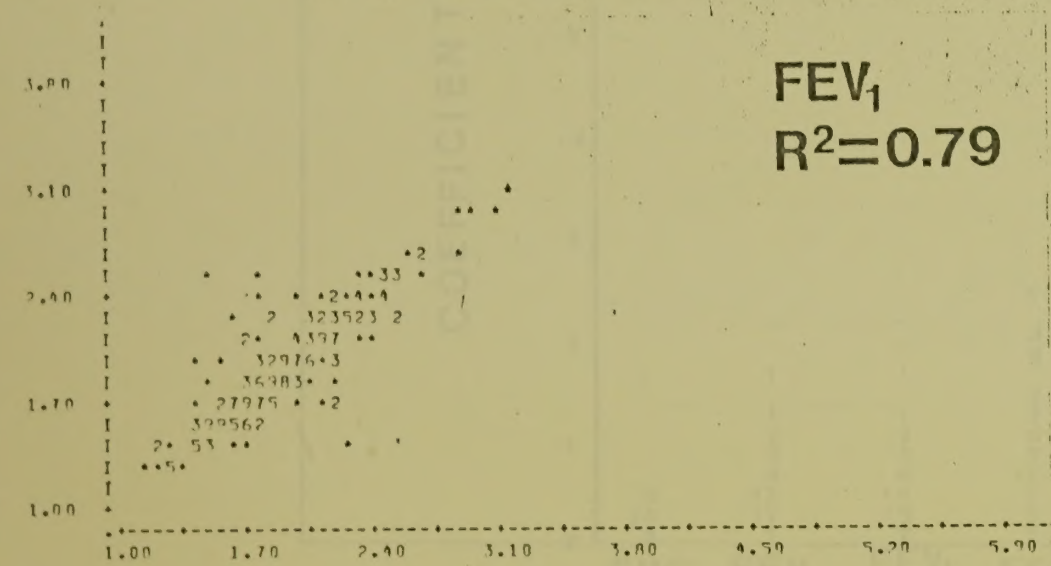




SCATTERGRAMS OF RETEST VALUES







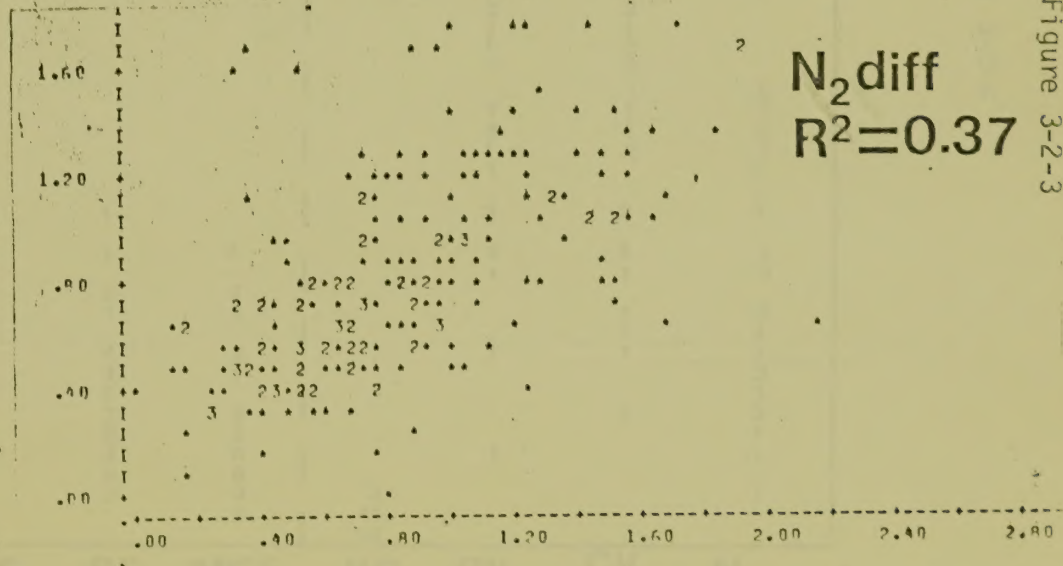


Figure 3-2-3

DISTRIBUTION OF COEFFICIENTS OF VARIATION
for variables obtained from the FVC and NWs manoeuvers

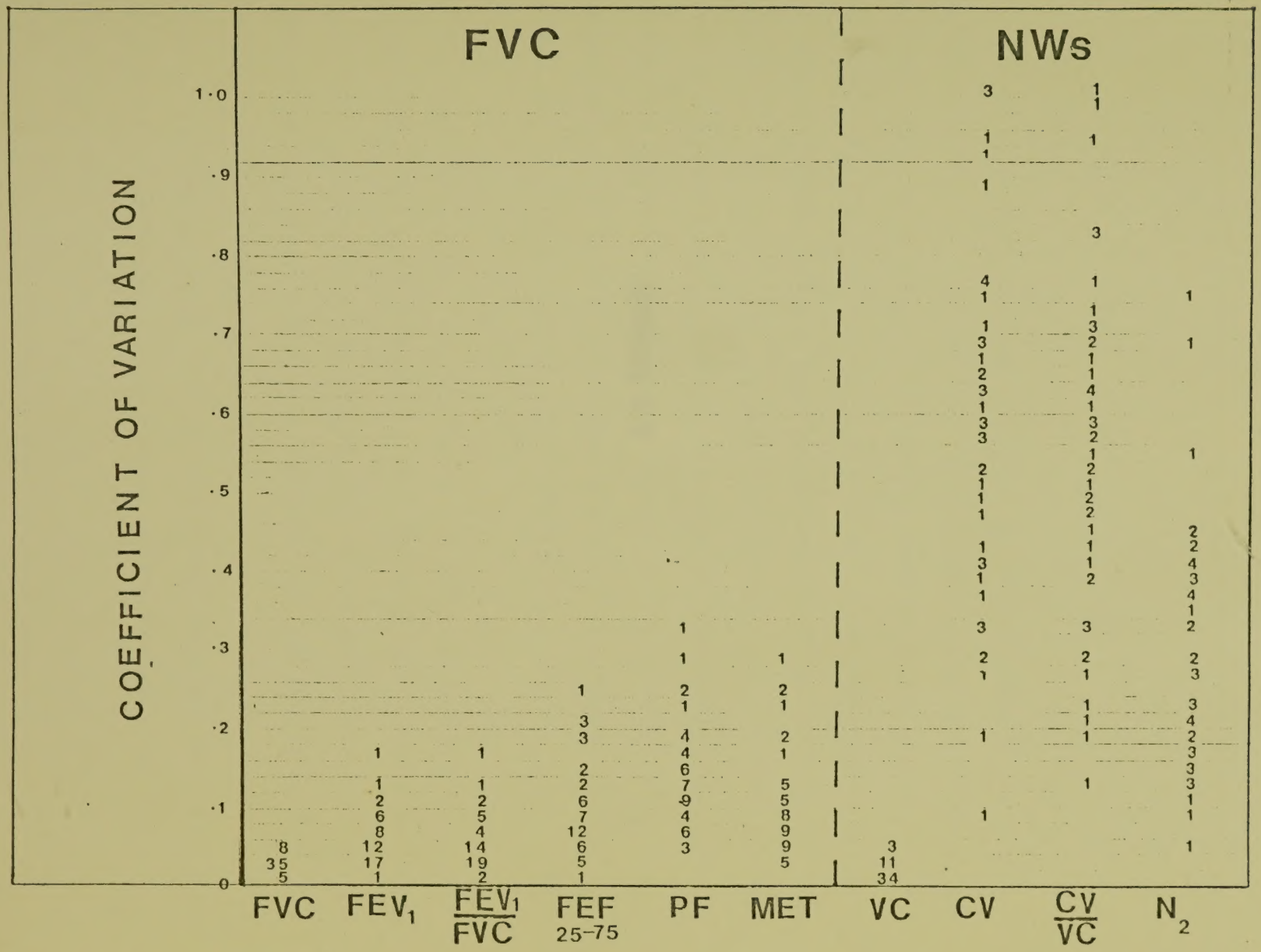


Figure 3-2-4

DISTRIBUTION OF COEFFICIENTS OF VARIATION

to examples using the EVC and MWe methods

APPENDIX 3-3

APPENDIX 3-3

NWm SUBSTUDY

As of February 23, 1981 we started an investigation into the reproducibility of the FRC and IDI measurements obtained from the NWm test. In January and early February, we had encountered problems when using the nitrogen subsystem of the H-P Pulmonary Calculator System. Upon occasion, a higher scatter of nitrogen values occurred during the washout than we were really willing to accept without an investigation. We decided to examine these variables to see if their reproducibility was affected by the quality of the test as judged subjectively by our technicians.

In four schools, two for System A and two for System B, each child was given to NWm tests. The FRC and IDI values for both were coded. Each test was also judged subjectively by the technician as 'good' (i.e., no scatter of the falling N_2 levels), 'questionable', (i.e., a little scatter), and 'poor', (i.e., tests which would be unacceptable unless the child had respiratory problems). These were coded as one, two and three, respectively.

The number of children so tested was 435, 181 by Team A and 254 by Team B. We examined scattergrams of FRC and IDI for

all the children, for Team A, for Team B, for children whose two tests were 'good', whose two tests were both 'bad', and whose two tests were very different, ie. one 'good' and one 'bad'. We also calculated the linear regressions, and looked at the R^2 values as an index of the reproducibility of the two tests. (See Table 3-3-1). We found that the reproducibility of FRC was similar for both Teams, and unaffected by the subjective quality of the test. We found R^2 values for the IDI very much lower than for the FRC. The one exception was for the children both of whose tests were 'bad'. On examining the scattergram (Figure 3-3-1), it can be seen that this was due to a few extremely high values for some children for both tests. One would expect to find such high values for IDI in lungs where there was some obstruction. This would also result in a wide scatter of N_2 values, which could explain the coding of these tests as 'poor'. By comparison, it can be seen that IDI values from the 'good' tests (Figure 3-3-2) are lower. Low values, with no scatter of the N_2 values, are characteristic of healthy lungs. We noted the very small number of children (n=14) who had one 'good' and one 'bad' test. This confirmed the subjective feeling of the testers that test quality was a function of the child, and that repeating tests did not often change this.

As a result of this investigation, we feel that the appearance of scatter in a NWm test does not affect the reproducibility of variables obtained from that test. It probably represents

physiological characteristics of the child tested, rather than abberent behaviour on the part of the equipment. We therefore feel confident that values obtained from such tests can be accepted into the data.

APPENDIX 3-4

CANADIAN SOCIETY OF PULMONARY AND CARDIOVASCULAR TECHNOLOGISTS
ANNUAL SEMINAR OCTOBER 1981

MULTIPLE-BREATH NITROGEN WASHOUT (NWm) AS AN EPIDEMIOLOGICAL SURVEY TOOL IN CHILDREN

ABSTRACT

E.M. INMAN, URBAN AIR ENVIRONMENT GROUP
MCMASTER UNIVERSITY, HAMILTON, ONTARIO

As part of our investigation into the effect of the environment on the respiratory health of schoolchildren, we have been assessing Pulmonary Function on 3000 children a year, initially ages 7-10 years. Forced Vital Capacity (FVC), single breath nitrogen washout (NWs) and multiple breath nitrogen washout (NWm) were obtained, using the Hewlett Packard pulmonary calculator system. We have made a comparative study of the tests we use, in terms of their practicality, validity, sensitivity, specificity and reliability. We found that most children were able to perform the breathing manoeuvres required for the NWm. Of the six indices of pulmonary function obtained from the NWm, only the IDI was able to distinguish a subgroup of children diagnosed by questionnaire data as having respiratory problems, whereas eleven indices from the FVC were able to do so. In 400 children in whom duplicate NWm tests were made, the IDI was found to be less reproducible than the FRC, and very much less so than most indices from the FVC. Subjects with an increased IDI in year one were re-examined in year two. A very large proportion failed to produce high levels for the second year. Those children who did have consistent high IDIs tended also to have a lower FEV_1/FVC ratio, suggesting that increased IDI does not identify a different population of subjects. The additional equipment needed to measure NWm is costly and more prone to failure than that for the FVC. For the above reasons our opinion is that the NWm is much less useful as a survey tool than the simpler more reliable FVC.

APPENDIX 3-5

ease complete this form by placing an "X" in the rrect box.

one will know whose form this is, it is a secret.

Have you ever smoked?

☐ YES ☐ NO

If yes, go to Question 2.
If no, go to Question 5.

Have you smoked in the last four weeks?

☐ YES ☐ NO

If yes, go to Question 3.
If no, go to Question 5.

How many cigarettes do you usually smoke in a week?

☐ less than 1 ☐ 1-10 ☐ more than 10

At what age did you smoke your first cigarette?

☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ 13 ☐ over 13

Does your mother smoke?

☐ YES ☐ NO ☐ CAN'T ANSWER

Does your father smoke?

☐ YES ☐ NO ☐ CAN'T ANSWER

FOR OFFICE USE ONLY

☐ 30

☐ 31

☐ 32

☐☐ 33 34

☐ 35

☐ 36

FOR OFFICE USE ONLY

7. Do you cough in the morning not counting just clearing your throat?

☐ YES ☐ NO

37

If yes, go to Question 8.
If no, go to Question 9.

8. Do you cough like this most mornings for as much as three months in a row each year?

☐ YES ☐ NO

38

9. Do you usually cough during the day or night, not counting just clearing your throat?

☐ YES ☐ NO

39

If yes, go to Question 10.
If no, go to Question 11.

10. Do you cough like this most days or nights for as much as three months in a row each year?

☐ YES ☐ NO

40

11. Does your chest ever sound wheezy or whistling?

☐ YES ☐ NO

41

12. Have you suffered from an attack of asthma in the last year?

☐ YES ☐ NO

42

13. When you have a cold, does it usually go to your chest?

☐ YES ☐ NO

43

APPENDIX 6-1

Appl. Phys. B26, ●●●–●●● (1981) 1-8

Applied Physics

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Second-Harmonic Detection with Tunable Diode Lasers – Comparison of Experiment and Theory*

J. Reid and D. Labrie

Departments of Engineering Physics and Physics, McMaster University, Hamilton, Ontario, Canada L8S 4M1

Received 24 February 1981/Accepted 11 May 1981

Abstract. A series of experiments are carried out by current modulating a tunable diode laser, and slowly ramping the wavelength to scan weak absorption lines in gases at pressures ranging from 2 to 60 Torr. A lock-in amplifier detects the second harmonic ($2f$) of the modulation frequency, and the experimental $2f$ signals are compared with theory. Detailed measurements are made on Lorentzian, Voigt, and Gaussian line profiles, over a wide range of modulation amplitudes. Excellent agreement between experiment and calculation is obtained in all cases. This quantitative understanding enables one to derive true lineshapes and linewidths of very weak absorption lines from measurements of $2f$ lineshapes only. Results are applicable to trace gas detection using tunable diode lasers, and to other areas of spectroscopy and magnetic resonance where harmonic detection techniques are routinely employed to monitor weak signals.

PACS: 07.65, 42.80

Harmonic detection is an experimental technique that is widely used to monitor weak signals in studies of electron and nuclear magnetic resonance, Zeeman and Stark spectroscopy, and acousto-optical spectroscopy. In recent years, harmonic detection has been used with tunable diode lasers (TDLs) to measure infrared absorption coefficients as small as $10^{-7}\,m^{-1}$ [1–3]. The basic principle of harmonic detection is the same in all the above applications. In general, the signal is modulated at high frequency (by varying the magnetic field in magnetic experiments, or the current of a TDL) and the instrument is tuned slowly past the signal feature of interest. The detector output is processed by a lock-in amplifier referenced to the modulation frequency, or some multiple thereof. This type of detection results in a significant improvement in signal-to-noise-ratio (SNR), but also produces an output signal that can only be related to the original feature by a mathematical transform. In this paper, we are concerned with infrared spectroscopy of gases, where the features of interest are isolated absorption lines. These absorption lines generally satisfy a Voigt profile but in the low and high pressure limits they can be approximated by Gaussian and Lorentzian lineshapes, respectively.

Several theoretical investigations have been carried out to determine the relationship between harmonic signals and Gaussian and Lorentzian lineshapes, for arbitrary amplitudes of sinusoidal modulation. Wahlquist [4] and Arndt [5] have determined analytic solutions for all the harmonic components of a Lorentzian lineshape. Wilson [6] employed numerical integration to obtain the first three harmonics for both Gaussian and Lorentzian absorption lines. However, we have been unable to find any detailed *experimental* confirmation of these formulae, despite the widespread use of harmonic detection techniques in experimental spectroscopy. Hence, one objective of this paper is to verify the above theories of harmonic detection by presenting a detailed comparison between calculated and experimental harmonic signals.

The experiments are carried out by current modulating a TDL, and tuning it across weak absorption lines in gases at pressures ranging from 2 to 60 Torr. The

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1907

second objective of the paper is to determine the modulation characteristics of TDLs, and thus enable us to *systematically* optimise detection parameters such as modulation amplitude, modulation frequency and gas pressure in experiments involving harmonic detection with TDLs. Experimental results are limited to *second*-harmonic detection and sinusoidal modulation, which were found to give optimum SNR in previous investigations of trace gas detection [1–3]. Theory and experiment are compared over a wide range of modulation amplitudes, and results are not confined to the "derivative spectroscopy" approximation at small amplitudes of modulation [7, 8]. Very good agreement between theory and experiment is found for Lorentzian, Voigt and Gaussian line profiles. This good agreement enables us to perform inverse transformations from harmonic signals to original lineshapes and, for example, measure the linewidth of absorption lines which are too weak to detect other than by harmonic techniques.

1. Theory

The theory described below is derived for the specific case of a wavelength tunable diode laser operating in the infrared (4–15 μm). However, by a simple change of variable (e.g., from wavelength to magnetic field) the theory can be adapted to all the cases described above.

The intensity $I(\nu)$ of an electromagnetic wave of frequency ν passing through a cell of length L filled with an absorbing gas is given by

$$I(\nu)=I_0(\nu)e^{-\alpha(\nu)L}, \tag{1}$$

where $I_0(\nu)$ and $\alpha(\nu)$ are the incident intensity and the absorption coefficient of the gas at frequency ν. In harmonic detection, one is only concerned with weak absorption lines, and consequently there is no loss of generality if the analysis is confined to values of $\alpha(\nu)L$ such that

$$\alpha(\nu)L \lesssim 0.05 \tag{2}$$

and the transmitted intensity can be approximated as

$$I(\nu)\simeq I_0(\nu)[1-\alpha(\nu)L]. \tag{3}$$

To produce the harmonic signals using a TDL, a sinusoidal modulation of angular frequency ω is superimposed upon the diode current.

This results in a time variation of the diode frequency given by the following expression

$$\nu(t)=\bar{\nu}+a\cos\omega t. \tag{4}$$

The mean frequency $\bar{\nu}$ is slowly tuned by ramping the diode current. In this analysis, we assume that the incident laser intensity is independent of frequency ν over the narrow range of frequency required to modulate and tune over an isolated line, i.e.,

$$I_0(\nu)\simeq I_0(\nu_0)\simeq I_0, \tag{5}$$

where ν_0 is the infrared frequency at line centre. This assumption is a good approximation in TDL experiments provided moderate amplitudes of modulation are employed [9]. The time dependent term of $I(\nu(t))$, $\alpha(\bar{\nu}+a\cos\omega t)$, is an even function of time and can be expanded in a cosine Fourier series.

$$\alpha(\bar{\nu}+a\cos\omega t)=\sum_{n=0}^{\infty} H_n(\bar{\nu})\cos n\omega t, \tag{6}$$

where $\bar{\nu}$ is considered to be constant over a modulation period. $H_n(\bar{\nu})$ is the nth Fourier component of the modulated absorption coefficient. If the laser beam exiting the absorption cell is focussed onto an IR detector, then the individual Fourier components can be selected by using a lock-in amplifier set to detect at the nth harmonic of the modulation frequency. In this case, the processed signal is proportional to

$$I_0 H_n(\bar{\nu})L, \quad n\geqq 1. \tag{7}$$

If the modulation amplitude a is sufficiently small the Fourier components can be expressed as [6]

$$H_n(\bar{\nu})=\frac{2^{1-n}}{n!}a^n\left.\frac{d^n\alpha(\nu)}{d\nu^n}\right|_{\nu=\bar{\nu}}, \quad n\geqq 1. \tag{8}$$

This small amplitude limit is often referred to as derivative spectroscopy, as the output signals are proportional to the derivatives of the absorption line. However, for such small values of a, the absolute values of $H_n(\bar{\nu})$ lie far below their maxima. We are more concerned with values of a which maximise the harmonic signals, and consequently optimise SNR while detecting weak absorption coefficients. For these optimum modulation amplitudes, the simplified expression (8) becomes inappropriate, and one must consider specific lineshapes individually.

First, let us consider the case where the gas pressure is sufficient to ensure that pressure broadening dominates. Then $\alpha(\nu)$ is described by a Lorentzian function

$$\alpha^L(\nu)=\frac{1}{1+\left[\dfrac{\nu(t)-\nu_0}{\Delta\nu}\right]^2}, \tag{9}$$

where $\Delta\nu$ is the half width at half maximum (HWHM) of the absorption line, and the absorption coefficient at line centre is normalised to unity. Following Arndt's

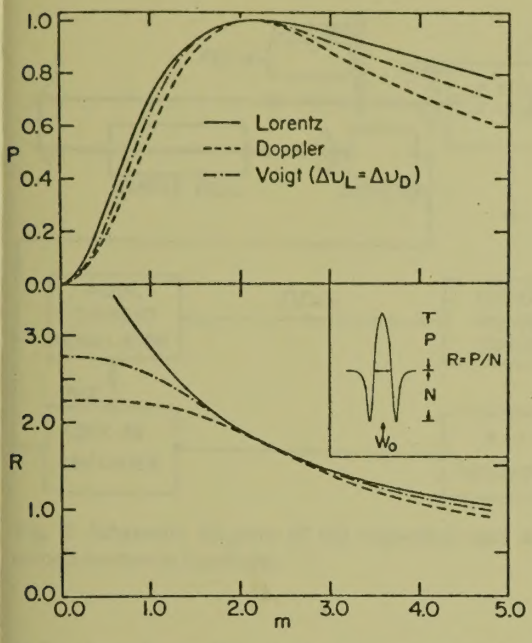


Fig. 1. Calculated properties of the second-harmonic (2f) lineshape for Lorentzian, Doppler and Voigt absorption lines. The insert shows a typical 2f lineshape as one tunes in frequency across the absorption line. P and R, as defined in the insert, are plotted as a function of modulation amplitude m for all three lineshapes. The peak value of (P_{max}) occurs at $m = 2.2$ in each case. P_{max} is normalised to unity for each lineshape when plotting the upper curves. (The actual values of P_{max}, as given by the respective second Fourier component, are Lorentzian 0.343, and Doppler 0.438)

convention, let us define two dimensionless parameters [5]

$$x = \frac{\bar{\nu} - \nu_0}{\Delta\nu}, \tag{10}$$

$$m = \frac{a}{\Delta\nu}. \tag{11}$$

The absorption coefficient becomes

$$\alpha^L(x,m) = \frac{1}{1+(x+m\cos\omega t)^2}. \tag{12}$$

The calculation of each Fourier component of the absorption coefficient has been carried out by Wahlquist [4] and Arndt [5]. The result for the second Fourier coefficient is

$$H_2^L(x,m) = \frac{4}{m^2} - \frac{2^{1/2}}{m^2}\frac{(M+1-x^2)[(M^2+4x^2)^{1/2}+M]^{1/2}+4x[(M^2+4x^2)^{1/2}-M]^{1/2}}{(M^2+4x^2)^{1/2}}, \tag{13}$$

where $M = 1-x^2+m^2$.

The insert in Fig. 1 shows a typical plot of $H_2^L(x,m)$ as a function of x [10]. The maximum value of the second-harmonic signal (2f signal) occurs at line centre, $\bar{\nu} = \nu_0$. This maximum positive value is defined as P, and is plotted as a function of modulation amplitude m in the upper part of Fig. 1. Note that the maximum 2f signal, P_{max}, is obtained for a value of $m = 2.2$. In Fig. 1 we also introduce the parameters N, R and W_0. N is defined as the peak negative excursion of the 2f lineshape from the baseline, and R is the ratio P/N. This ratio is a very useful experimental parameter, and its variation with m is plotted in the lower part of Fig. 1. Also shown in Fig. 1 are theoretical plots of P and R for Gaussian and Voigt lineshapes, calculated by the methods described below.

The Lorentzian lineshape discussed above is a good approximation at gas pressures where pressure broadening is dominant. If the gas pressure is reduced such that pressure broadening is negligible, and Doppler broadening is dominant, $\alpha(x,m)$ is given by a Gaussian function

$$\alpha^G(x,m) = \exp[-\ln 2(x+m\cos\omega t)^2]. \tag{14}$$

Wilson [6] has carried out a calculation of $H_2^G(x,m)$ using numerical integration of the Fourier integrals. We used the same method to calculate the properties of the second-harmonic signal employing the following equation for $H_2^G(x,m)$

$$H_2^G(x,m) = \frac{2}{\pi}\int_0^{\pi} \exp[-\ln 2(x+m\cos\theta)^2]\cos 2\theta\, d\theta. \tag{15}$$

Results obtained for the variation of P and R with m are shown in Fig. 1.

Finally, one can consider the intermediate case where both Doppler and pressure broadening are important, i.e.,

$$\Delta\nu_L \sim \Delta\nu_D, \tag{16}$$

where the subscripts L and D represent Lorentzian and Doppler, respectively. The normalised absorption coefficient for this case is given by

$$\alpha^V(y,z) = V(y,z)/V(0,z), \tag{17}$$

where $z = \Delta\nu_L/\Delta\nu_D\sqrt{\ln 2}$, $y = z(\nu-\nu_0)/\Delta\nu_L$ and $V(y,z)$ is the Voigt function [11]. We used the Humlicek algorithm [12] for the Voigt function to calculate the properties of the 2f lineshape. The second Fourier component of the Voigt lineshape $H_2^V(x,m)$ is calculated numerically from the expression

$$H_2^V(x,m) = \frac{2}{\pi}\frac{1}{V(0,z)}\int_0^{\pi} V((x+m\cos\theta)y_{1/2},z)\cos 2\theta\, d\theta, \tag{18}$$

where $y_{1/2}$ is obtained from $V(y_{1/2},z) = V(0,z)/2$. Once again, results for P and R are plotted in Fig. 1.

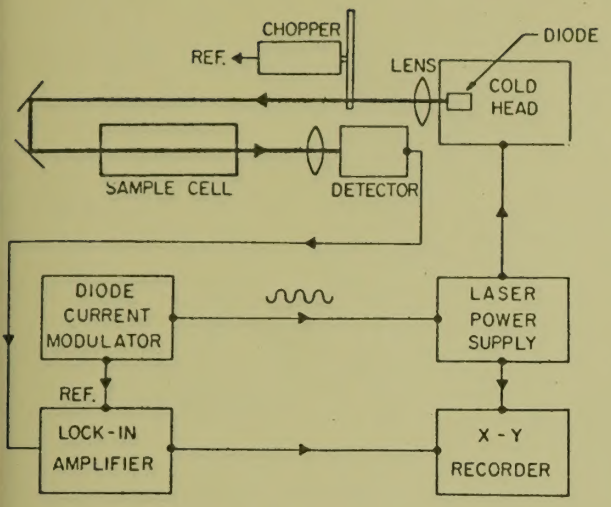


Fig. 2. Schematic diagram of the apparatus used to investigate second-harmonic lineshapes

It is clear from Fig. 1 that the general behaviour of Gaussian, Voigt and Lorentzian lineshapes is similar. In particular, all three lineshapes give a maximum 2f signal at line centre for a modulation $m=2.2$, and have identical values of R for this modulation value. The differences between Lorentzian and Gaussian lineshapes are most apparent at large and small values of m. In the next section, a detailed comparison is made between the theory described above and experimental results for all three lineshapes.

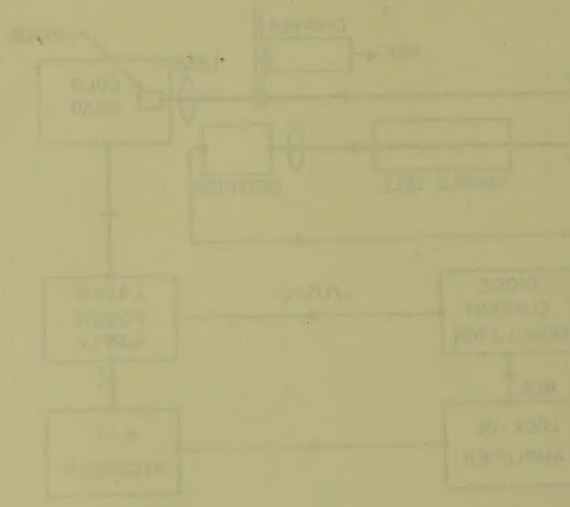
2. Experimental Apparatus and Technique

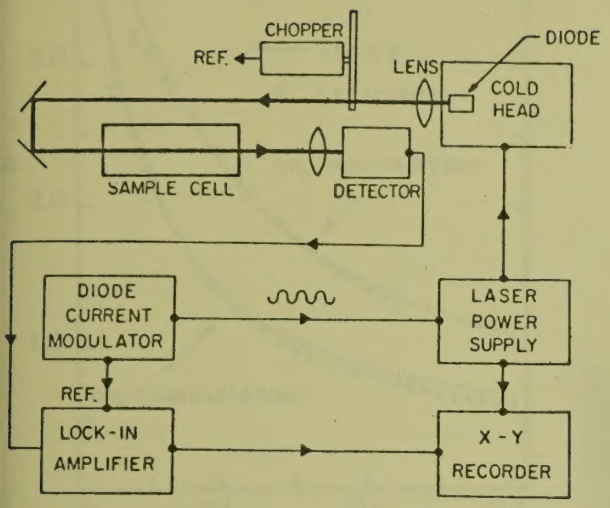
The experimental apparatus is illustrated schematically in Fig. 2. The TDL is mounted in a closed cycle refrigerator and can be temperature controlled in the range 10 to 70 K. Coarse adjustment of the laser wavelength is carried out by changing the diode temperature, while variation of the drive current to the diode laser allows fine control of both the laser wavelength and mode structure. We used three different diode lasers emitting at wavelengths from 4.5 μm to 7.3 μm. In most cases the diode lasers were operated in a single mode, but experiments were also carried out with multi-mode lasing to ensure that the results obtained can be applied to typical TDL operation. The laser output is collected by an $f/1$ lens and focussed into a 10 cm absorption cell. Measurements were performed on isolated absorption lines in gases such as SO_2(7.3 μm), CO_2(4.5 μm), and NO(5 μm). Gas pressures were varied from 2 to 60 Torr, and peak absorptions at line centre were limited to $\lesssim 5\%$. The output beam from the absorption cell is focussed onto a HgCdTe detector. For direct detection of infrared absorption lines an external chopper and lock-in amplifier are used to synchronously detect the transmitted laser power. Second-harmonic detection is obtained by removing the mechanical chopper and applying a sinusoidal modulation (frequency: 0.5 to 10 kHz) from an external signal generator to the diode drive current. The applied modulation amplitude was measured with an ac digital voltmeter. The signal generator also supplies a reference signal to the lock-in amplifier, which is set to detect at twice the modulation frequency. All data were recorded on an X–Y plotter, and measurements were made from the recorded traces. For all TDLs we checked that the laser wavelength varies linearly with current. This was accomplished by placing a Ge etalon (7.65 cm long) or reference gas cell in the laser beam. All TDLs displayed a linearity of better than 1% over the limited tuning range required for the experiments described below.

2.1. *Lorentzian Lineshapes – Comparison of Theory and Experiment*

The initial series of experiments were designed to check the analytic expression given in (13). A TDL operating in a single mode near 1350 cm^{-1} was used in conjunction with SO_2 as the absorbing gas. A mixture of SO_2 and N_2 was placed in the 10 cm absorber cell, and the SO_2 concentration adjusted to give a few percent absorption on the strongest SO_2 lines. Total pressure was set at 15 Torr. This pressure is a compromise between a true pressure-broadened line and the problems of line overlap and diode modulation distortion which occur at higher pressures (and therefore larger modulation amplitudes). At 15 Torr in an SO_2/N_2 mixture, $\Delta\nu_L \sim 2.6\Delta\nu_D$, and the lineshape is a close approximation to a true Lorentzian. A relatively isolated SO_2 line at 1349.537 cm^{-1} [13] was chosen, and several 2f lineshapes were plotted as the modulation amplitude and frequency were varied. For all traces, the lock-in amplifier phase settings were chosen to maximise the 2f signal, and care was taken to avoid any distortion due to the time constant employed [14].

We first examined the variation of the ratio R (Fig. 1) as a function of modulation voltage A (measured in rms volts). Experimentally, R is a very convenient parameter to use as it can be measured directly from the X–Y recorder traces without calibration of either the X or the Y axis, and is independent of the laser power. Results are shown in Fig. 3 for two different values of the modulation frequency, F_0. Typical error bars are indicated on several data points. Also shown in Fig. 3 is a calculated curve of R, obtained using (13). To display these curves we have assumed that the normalized modulation amplitude m is proportional to the applied voltage modulation A. Clearly, good agree-





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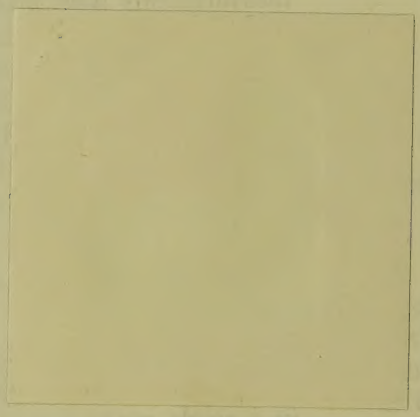


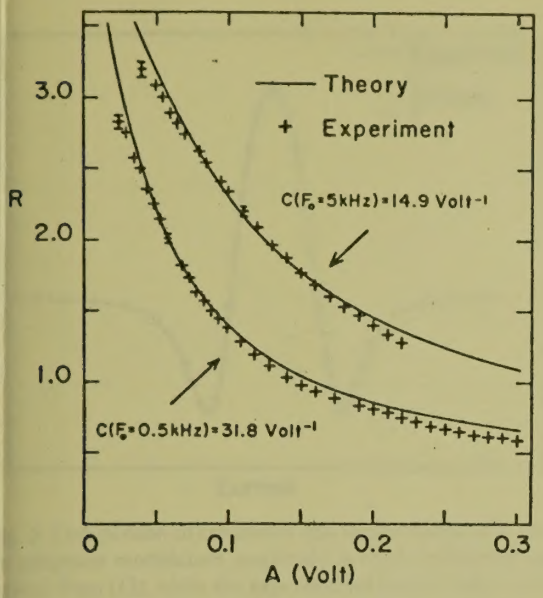


Fig. 3. Plot of the ratio R (Fig. 1) as a function of the modulation amplitude A for two values of the modulation frequency. Also shown are calculated curves fitted to the experimental results assuming a linear relationship between A and the wavelength modulation parameter, m. The proportionality constant $C = m/A$ is also given

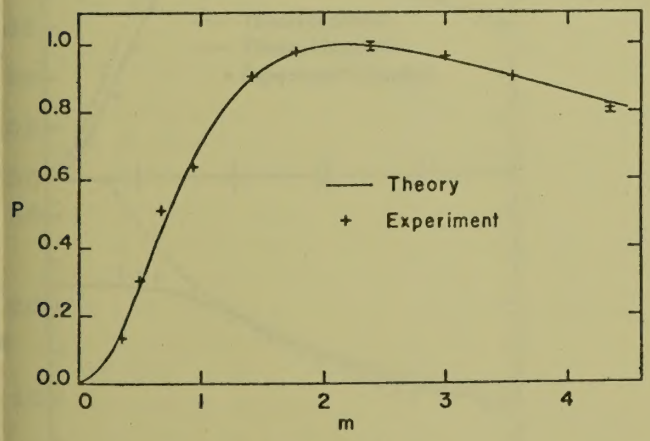
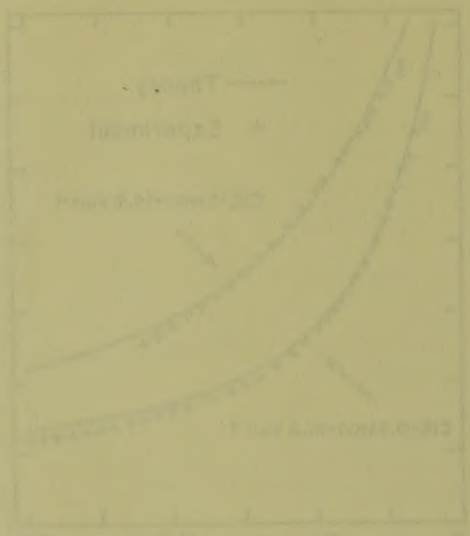


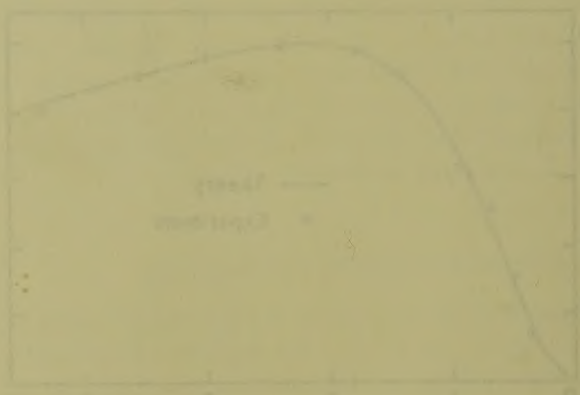
Fig. 4. Plot of the positive part of the 2f lineshape, P, as a function of m for both theory and experiment. The experimental value of m is determined from a simultaneous measurement of the ratio R (see text). The maximum value of P is normalised to unity for both theory and experiment

ment over the entire range of A values supports this assumption, and the process of fitting the best calculated curve to the experimental results enables one to determine the constant of proportionality, $C = m/A$. The corresponding values of C are indicated on Fig. 3. It is of interest to compare the wavelength modulation attained at high frequencies with the dc value. For the 7.3 μm TDL, the dc tuning rate was 11 cm^{-1}/A, measured with the Ge etalon and a slow current ramp. At modulation frequencies of 500 Hz and 5 kHz, the C values determined in Fig. 3 can be converted to equivalent tuning rates of 7.4 and 3.5 cm^{-1}/A, respectively [15]. This decrease in tuning rate as F_0 increases is consistent with the thermal time constant involved in the diode tuning mechanism. A second TDL with a dc tuning rate of 38 cm^{-1}/A gave an equivalent tuning rate of 14 cm^{-1}/A for a modulation frequency of 3 kHz. Clearly, this behaviour limits the range of modulation frequencies at which significant wavelength modulation can be obtained without undue distortion. As the inherent amplitude noise of TDLs drops off quickly at high frequency [16], an optimum modulation frequency exists for maximum SNR. Typically, this optimum value lies in the range 1 to 5 kHz [1–3].

While the overall agreement between theory and experiment displayed in Fig. 3 is very good, there are small systematic discrepancies at both small and large values of A. At large A, the amplitude of modulation is sufficient to violate the approximation expressed in (5), i.e., the modulated output of the TDL becomes visibly distorted when observed directly on an oscilloscope. In addition, the wavelength modulation is sufficient to encroach upon the wings of nearby weak SO_2 lines, and slightly distort the 2f lineshape. The discrepancy at low values of A is more fundamental, and arises from the small Gaussian component remaining in the SO_2 lineshape. By comparison with Fig. 1, one can see that any slight departure of the experimental lineshape from a pure Lorentzian will result in reduced values of R at small m, in agreement with experiment.

In addition to confirming the theoretical expression (13), the results shown in Fig. 3 enable us to convert from the experimental parameter A to the more fundamental modulation amplitude m. Figure 4 shows experimental measurements of P plotted against the value of m as determined from Fig. 3. The same SO_2 line at 1349.537 cm^{-1} was used with a modulation frequency of 500 Hz. For each data point, the value of P measured on the X–Y recorder was normalized to the total laser power. Also shown on Fig. 4 is the calculated variation of P as a function of m. There is good agreement over the entire range of modulation amplitudes. As a final check of the theory of Lorentzian lineshapes, we compared an experimental and a calculated 2f lineshape. A TDL emitting near 4.5 μm was used in conjunction with an absorption cell containing 55 Torr $CO_2(\Delta\nu_L \sim 3.0\Delta\nu_D)$ for this experiment. The wavelength modulation parameter m was set at 2.2 to maximise P, and a slow scan taken of the entire 2f lineshape. This X–Y recorder trace is displayed in Fig. 5, and superimposed upon it is a calculated curve of $H_2^L(x, 2.2)$. Excellent agreement is obtained over the entire lineshape. All our results indicate that the expression for $H_2^L(x, m)$ given in (13) is repro-





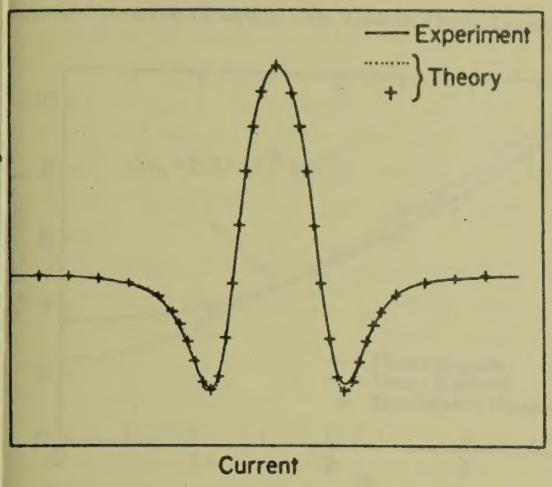


Fig. 5. Comparison of calculated and experimental 2f lineshapes for the optimum modulation amplitude m=2.2. Calculated values are derived from (13), while the experimental trace is taken on the X–Y recorder. A scaling factor is used on each axis to optimise the fit. Modulation frequency, $F_0=3$ kHz)

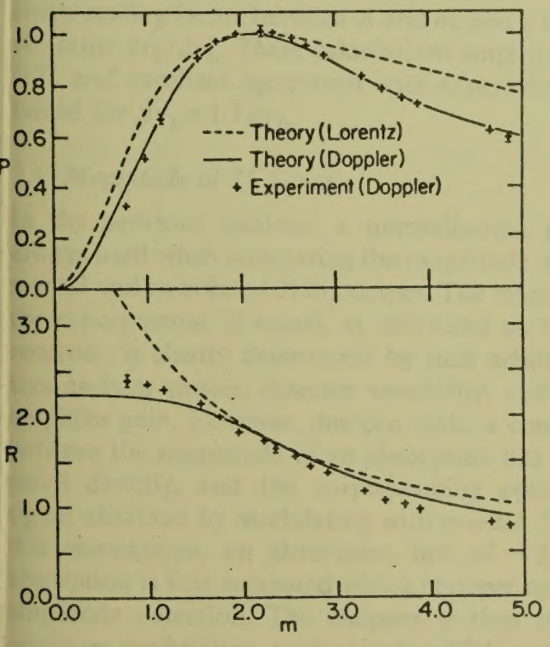


Fig. 6. Plot of calculated and experimental values of P and R as a function of m. The experimental points were obtained by scanning over a lineshape which is mostly Doppler broadened ($\Delta\nu_D=7.7\Delta\nu_L$). Calculated curves are shown for both Lorentzian lineshapes, Eq. (13), and Gaussian lineshapes, Eq. (15)

duced within experimental error by modulated TDLs.

2.2. *Gaussian and Voigt Lineshapes: Comparison of Theory and Experiment*

To study a Doppler broadened line, we replaced the 10 cm absorption cell with a multipass cell capable of pathlengths to 40 m. A TDL emitting in a single mode

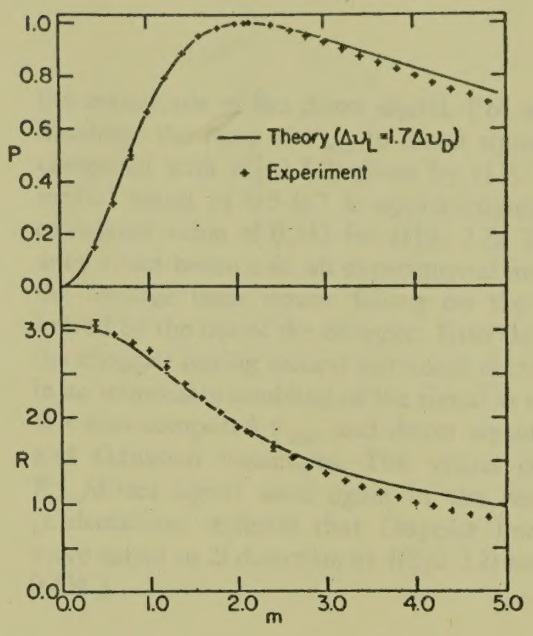
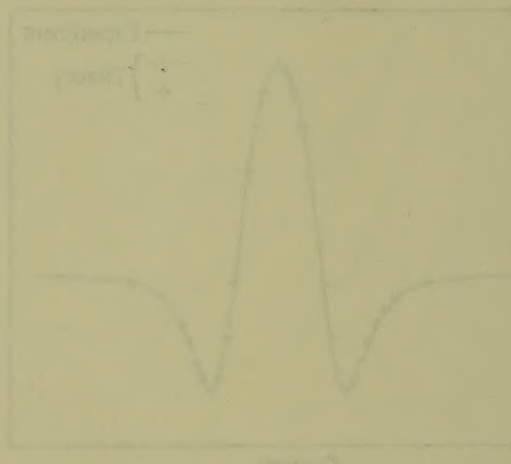


Fig. 7. Plot of calculated and experimental values of P and R as a function of m for an absorption line with a Voigt profile. Calculated curves are based on (17), and use a best-fit value of $\Delta\nu_L/\Delta\nu_D=1.7$

near 2200 cm^{-1} was tuned over an isolated absorption line in pure CO_2 at 2.4 Torr pressure ($\Delta\nu_D=7.7\Delta\nu_L$). Once again measurements were made of P and R as a function of modulation amplitude A. Results are shown in Fig. 6, and are compared with calculated curves for both pure Doppler and pure Lorentzian broadened lines. The same value of $C(=m/A)$ was used to plot each set of results. Reasonable agreement is observed between theory and experiment over the entire range of modulation. The experimental values of R deviate slightly from the pure Doppler curve at low modulation amplitude. We interpret this deviation as being caused by the residual pressure broadened component of our experimental lineshape ($\Delta\nu_D=7.7\Delta\nu_L$). Once again, we attribute the small discrepancies observed at high m values to TDL distortions which make (5) no longer exact.

The experimental results described above verify the theory of 2f lineshapes for both Lorentzian and Gaussian lines. As a final step, a brief investigation was made of the intermediate case, where a Voigt profile must be used to accurately describe lineshapes. A mixture of NO in N_2 was placed in the absorption cell and the total pressure was chosen such that $\Delta\nu_L\sim\Delta\nu_D$. A third TDL was used for this study, and was operated multimode such that only 50% of the output power tuned past the NO line near 1900 cm^{-1}. No mode selector was employed, and all laser modes were collected by the detector. The modulation frequency was 3 kHz. Experimental results for P and R are shown in Fig. 7. Also shown are calculated curves based on a



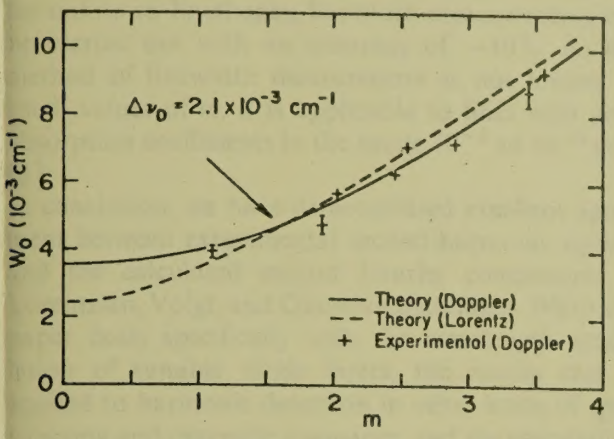


Fig. 8. Plot of experimental zero crossing separation W_0 as a function of m for a Doppler broadened line ($\Delta\nu_D = 7.7\Delta\nu_L$). Also shown are calculated curves for Doppler and Lorentzian lineshapes with $\Delta\nu = 2.1 \times 10^{-3}\,\mathrm{cm}^{-1}$ in each case

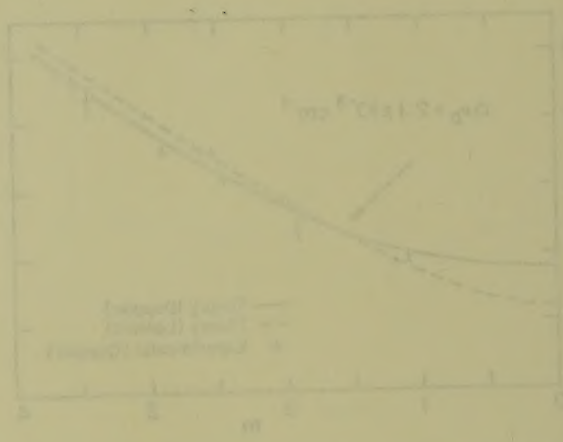
single scaling factor between A and m, and a best fit to the ratio $\Delta\nu_L/\Delta\nu_D$. These calculations employ (16) and (17), and excellent agreement with experiment is obtained for $\Delta\nu_L = 1.7\Delta\nu_D$.

2.3. *Magnitude of 2f Signals*

In the previous sections, a normalisation factor is always used when comparing the magnitude of experimental and calculated 2f lineshapes. The magnitude of the experimental 2f signal, as measured on the X–Y recorder, is clearly determined by such arbitrary factors as laser power, detector sensitivity, and lock-in amplifier gain. However, one can make a comparison between the magnitude of an absorption line as measured directly, and the corresponding optimum 2f signal obtained by modulating with $m = 2.2$. To make this comparison, an absorption line of ~5% peak absorption is first measured with a chopper and direct amplitude detection. The chopper is then removed, optimum modulation applied to the TDL, and a scan taken of the 2f lineshape. All operating conditions remain unchanged during the two measurements, other than a change in reference signal and phase setting of the lock-in amplifier. We routinely carry out this type of measurement on Lorentzian lineshapes as part of our calibration procedure for trace gas detection [1–3]. We find that the maximum value of the positive 2f signal, P_{max}, lies between 0.5 and 0.7 of the magnitude of the direct absorption signal. The variations in this ratio can be attributed to the following experimental conditions (i) the chopper and modulation frequencies are usually different and consequently the two signals often undergo slightly different amplification factors from detector to X–Y recorder, (ii) the exact position of the chopper in the laser beam affects the chopped waveform and hence the magnitude of the direct signal. For a Lorentzian lineshape the ratio of P_{max} to direct signal should be compared with $H_2^L(0, 2.2)$ given by (13). The experimental result of 0.5–0.7 is approximately twice the calculated value of 0.343 for $H_2^L(0, 2.2)$. This discrepancy arises because in all experimental measurements the average laser power falling on the detector is halved by the use of the chopper. Thus the removal of the chopper during second harmonic detection results in an immediate doubling of the signal at the detector. We also compared P_{max} and direct signals for Voigt and Gaussian lineshapes. The values of the ratio P_{max}/direct signal were again in the range 0.5–0.7. [Calculations indicate that Doppler lineshapes are more suited to 2f detection as $H_2^G(0, 2.2)$ has a value of 0.438.]

3. Discussion and Conclusions

The results described in the previous section confirm that the theoretical expressions derived in Sect. 1 are an accurate representation of experimental 2f lineshapes as observed with TDLs. Given this firm quantitative knowledge of the behaviour of the 2f lineshapes, one can systematically optimise experimental parameters to maximise SNR in trace gas detection, or to minimise interferences from nearby absorption lines in experiments on rare isotope detection [17]. In addition, by comparing calculated and measured 2f lineshapes one can perform an inverse transformation to determine the true lineshape of an absorption line which may be too weak to observe directly. By measuring the ratio R for modulation amplitudes in the range $m = 0$ to 2 one can estimate the degree of Doppler and pressure broadening in an unknown absorption line [7]. Once the lineshape is known, it is a relatively easy matter to determine the linewidth. To demonstrate this we have further analysed the 2f lineshapes recorded for Fig. 6, i.e., scans taken of an absorption line in 2.4 Torr pure CO_2. For each 2f lineshape, the value of m is known from the fit to P and R in Fig. 6. A measurement was also made of W_0, the zero crossing separation (Fig. 1). The dc tuning rate of the TDL is determined from etalon scans and a reference N_2O spectrum, and W_0 is readily converted to units of cm^{-1}. Figure 8 shows a plot of experimental W_0 values as a function of m. Also shown is the calculated variation of W_0 with m for both Gaussian and Lorentzian lineshapes. We have scaled the Gaussian curve to the experimental results and hence determine $\Delta\nu_D$ as $(2.1 \pm 0.1) \times 10^{-3}\,\mathrm{cm}^{-1}$. This is in good agreement with the calculated Doppler width of the CO_2 line, $2.0 \times 10^{-3}\,\mathrm{cm}^{-1}$ HWHM at room temperature. Note that the variation of W_0 with m is relatively



independent of the lineshape for $m > 1$. Therefore, even for unknown lineshapes, linewidth measurements can be carried out with an accuracy of $\sim 10\%$. As this method of linewidth measurement is not limited to small values of m, it is applicable to lines with peak absorption coefficients in the range 10^{-5} to $10^{-6}\,m^{-1}$ [3].

In conclusion, we have demonstrated excellent agreement between experimental second-harmonic signals, and the calculated second Fourier components of Lorentzian, Voigt, and Gaussian lineshapes. While this paper deals specifically with the wavelength modulation of tunable diode lasers, the results can be applied to harmonic detection in other areas of spectroscopy and magnetic resonance, and the calculations can easily be extended to include other harmonic components.

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APPENDIX 6-2

HIGH SENSITIVITY SPECTROSCOPY WITH TUNABLE DIODE LASERS - DETECTION OF O_2 QUADRUPOLE TRANSITIONS AND ^{14}C

J. Reid
Department of Engineering Physics
McMaster University
Hamilton, Ontario
Canada L8S 4M1

1. Introduction

In recent years, tunable lead-salt diode lasers (TDLs) have found widespread application in all fields of infrared spectroscopy. However, most applications of TDLs utilise only the tunability and high resolution of these devices, and few experiments have employed the ability of the TDL to detect very small absorption coefficients. We have developed a laser absorption spectrometer (LAS) which can detect absorption coefficients as small as 10^{-6} to 10^{-7} m^{-1}, while retaining the full tunability and resolution of the TDL. This instrument has been used as a point monitoring system for many trace gases of atmospheric significance [1-3]. In this paper, we describe two additional applications of the LAS: (i) the detection of very weak transitions such as quadrupole lines in oxygen, and (ii) the detection of rare isotopes, with ^{14}C in CO_2 as an example. Details are given in the following sections.

2. Experimental Apparatus

The LAS basically consists of a TDL and a multipass optical cell. Two f/1 Ge Lenses are used to focus the TDL beam into the multipass cell, and to refocus the output onto a HgCdTe detector. A detailed description of the apparatus is given in previous publications [1-3]. Initially, a monochromator is placed in the laser beam to characterise the TDL behaviour, and to select operating conditions which give regions of good single mode tunability. The monochromator is then removed as reflections from the input and exit slits seriously degrade the instrument performance.

Typical results obtained with a TDL operating near 1600 cm^{-1} are shown in Fig. 1. The diode tunes in a single mode until a mode hop occurs at 924 mA. For the lower trace, second harmonic detection was used to enhance sensitivity [1-3]. The two additional lines which appear in the air sample are identified as HDO lines from the AFGL compilation [4]. By tilting all optical components to avoid feedback, carefully optimising the optical alignment, and adding a second modulation to minimise the effect of optical fringes, the LAS noise level can be reduced until it is equivalent to an absorption coefficient of $\sim 2 \times 10^{-7}$ m^{-1}, or less than 100 ppt of NO_2 [3].

The NO_2 lines shown in Fig. 1 are conventional electric dipole transitions and have substantial linestrength. As an alternative to detecting NO_2 at low concentrations, one can clearly use the LAS to search for very weak transitions in a pure gas. An example is given in the next section.

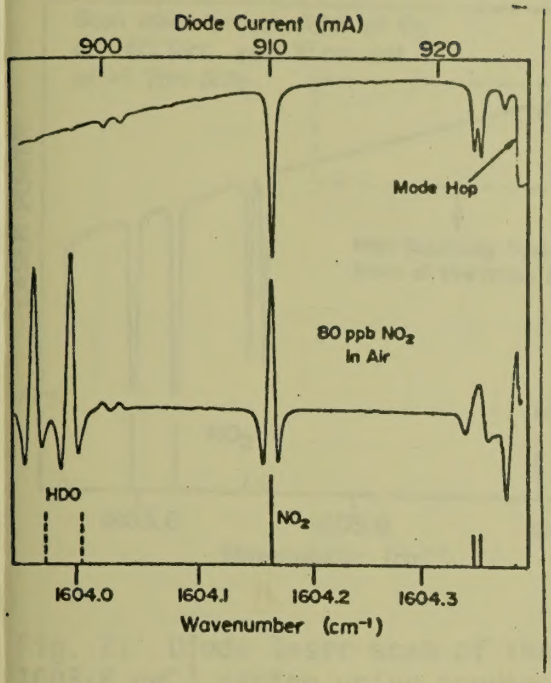


Fig. 1: Spectra of pure NO_2 and NO_2 in air. For the upper trace a 10-cm cell containing NO_2 at low pressure was placed in the laser beam, and conventional amplitude detection was employed. The lower trace was taken using second harmonic detection with the laser beam traversing a path length of 40 m in air at 30 Torr and a small calibration cell giving the equivalent of 80-ppb NO_2. The predicted HDO and NO_2 spectra are shown at the bottom of the figure [4,5].

3. Observation of Electric Quadrupole Transitions in O_2

The TDL used to produce the traces in Fig. 1 is ideally suited to study the v=1←0 vibration-rotation quadrupole band of O_2. At room temperature one of the strongest features in this band is the S(7) quadrupole line, which is expected to lie near 1603·8 cm^{-1} [6]. A further incentive to search for a weak O_2 transition in this region was provided by the recent observation of an unidentified line triplet at 1603·8 cm^{-1} in a long path infrared atmospheric spectrum reported by NIPLE et al. [7].

For the initial experiments, we used an NO_2 reference cell in addition to the 1m base pathlength White Cell, and set the TDL to reproduce the upper trace of Fig. 1. The diode heat sink temperature was then adjusted very slightly to enable the TDL to tune from 1603·5 cm^{-1} to 1604·1 cm^{-1} in a single mode. Results taken with conventional amplitude detection are shown in Fig. 2. The NO_2 reference cell was then removed, and a high sensitivity scan taken through 40 m of pure O_2 at 40 Torr using second harmonic detection. A distinct triplet appeared above the noise level, as shown in Fig. 3. We have unambiguously identified this triplet as the J=10←8, 9←7, and 8←6 spin components of the S(7) (N=9←7) quadrupole transition of $^{16}O_2$.

We have made careful measurements of the positions and line splittings of the O_2 quadrupole lines, and found good agreement between our results and previous measurements on the Raman and microwave spectra of O_2 [6]. The laboratory measurements also enabled us to confirm that the triplet observed by NIPLE et al. [7] is in fact the S(7) quadrupole transition of atmospheric oxygen. Similar agreement between laboratory and solar spectra was obtained for the S(5) quadrupole transition [6], and several quadrupole lines of N_2 have recently been observed in long-path atmospheric spectra.

4. Detection of Radiocarbon

The LAS has been used to examine the feasibility of dating carbon samples

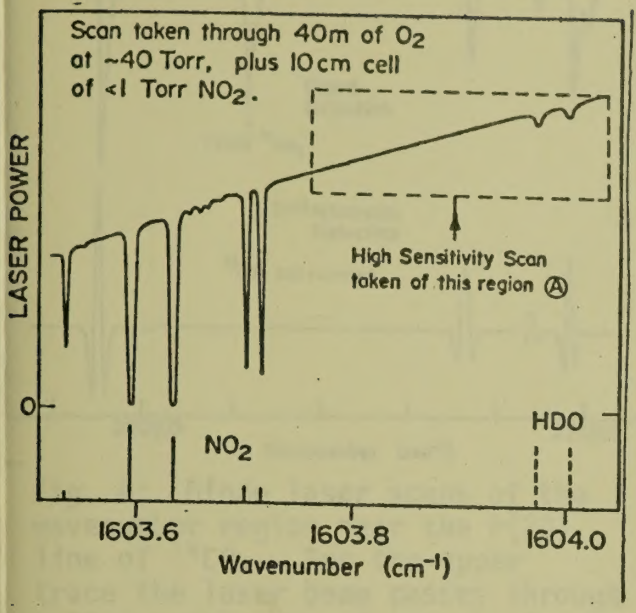


Fig. 2: Diode laser scan of the 1603.8 cm^{-1} region using conventional amplitude detection. Calculated line positions, shown at the bottom of the figure, are taken from the AFGL tapes [4,5].

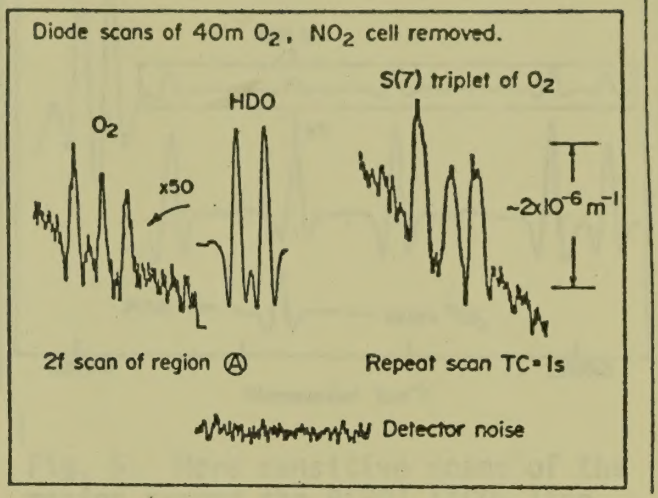
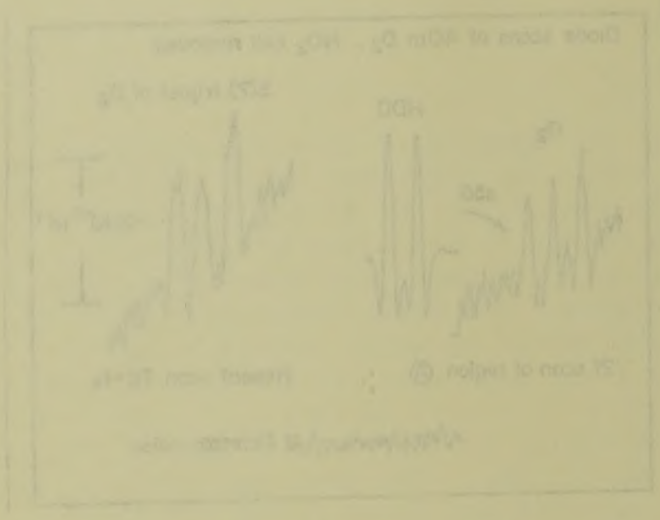
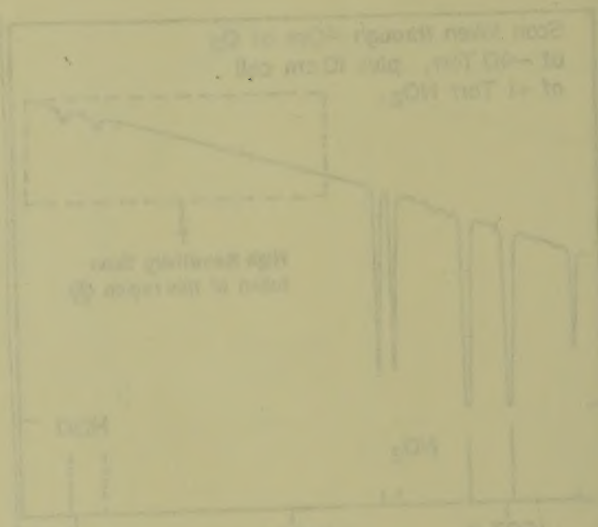


Fig. 3: High sensitivity scans of the S(7) triplet of O_2 in region A of Fig. 2. The sensitivity is close to detector noise limited due to the relatively low power available in this laser mode.

using infrared spectroscopy. We propose to convert the carbon sample to CO_2, and then measure the absorption coefficients of the strong vibration-rotation lines in the ν_3 band of $^{14}CO_2$ near 4.5 μm. Modern samples of carbon have a $^{14}C/^{12}C$ ratio of $\sim 10^{-12}$, and hence one must be able to detect less than 1 ppt ^{14}C in the presence of the stable isotopes of carbon and oxygen. This requires a careful choice of $^{14}CO_2$ absorption line to minimise the background interference from the lines of the stable isotopic species. We carried out a line-by-line evaluation of the P-branch of $^{14}CO_2$, and determined that the P(20) transition is one of the best lines for detection of $^{14}CO_2$ [8]. The upper trace of Fig. 4 shows a TDL scan made with a 32 m pathlength of normal CO_2 plus a small cell containing a sample of $^{14}CO_2$ to locate the P(20) line. Second harmonic detection is used for the lower trace, and expanded views of the P(20) region are shown in Fig. 5. Clearly, line B interferes with the $^{14}CO_2$ P(20) line, and poses a severe problem for radiocarbon dating, unless steps are taken to suppress the interference.

Fortunately, the ratio of interference linestrength to $^{14}CO_2$ linestrength shown in Fig. 5 only holds at room temperature. All weak lines in CO_2 in the 2209 cm^{-1} region are expected to be hot band lines, and should undergo a dramatic reduction in intensity if the CO_2 sample is cooled. To estimate the reduction in linestrength of line B upon cooling, one must know the energy of its lower level, E_L. We determined E_L by heating a sample of CO_2 and comparing the increase of absorption on line B with increased absorption on several lines of known E_L. In this manner E_L for line B was determined to be 3430 ± 150 cm^{-1}. This high value of E_L ensures that there will be a very substantial reduction in the interference on cooling the CO_2 sample. Thus, we are confident that the detection of $^{14}CO_2$ in a cooled multipass cell will not be limited by interferences from the stable isotopic forms of CO_2.





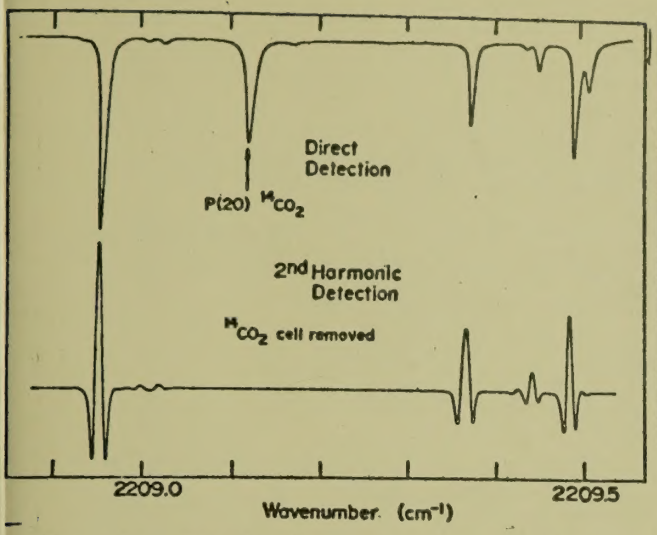


Fig. 4: Diode laser scans of the wavenumber region near the P(20) line of $^{14}CO_2$. For the upper trace the laser beam passes through a 32 m pathlength of normal CO_2 at 20 Torr, followed by a small cell containing $^{14}CO_2$.

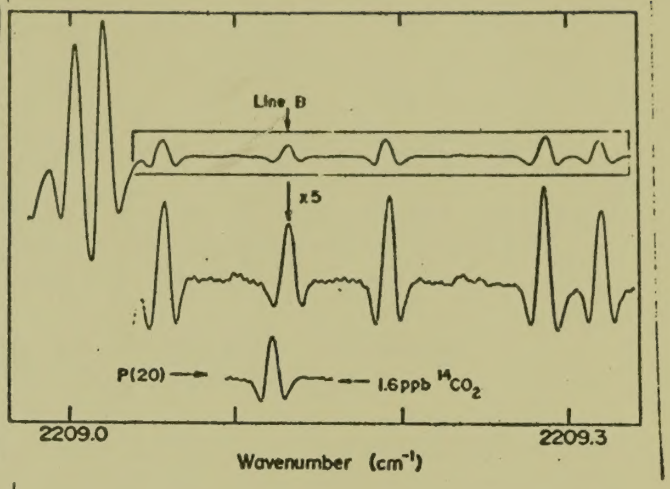


Fig. 5: More sensitive scans of the region around the P(20) $^{14}CO_2$ line. The weak line B is present in normal CO_2 and overlaps the P(20) $^{14}CO_2$ line which is represented by the trace at the bottom of the figure.

If infrared spectroscopy is to provide an alternative technique for radiocarbon dating, the experimental sensitivity must be sufficient to detect $^{14}CO_2$ at concentrations much less than 1 ppt. At present our noise level of $2X10^{-7}$ m^{-1} is equivalent to 10 ppt $^{14}CO_2$, but our results have been confined to 1 m multipass cells with time constants of 1s. Under these conditions, the LAS is more sensitive to ^{14}C than conventional disintegration counters. However, it remains to be seen whether the LAS results can be extrapolated to very long time constants and longer cells [8]. A combination of signal averaging and background subtraction techniques will be required to approach the sensitivities needed for practical radiocarbon dating.

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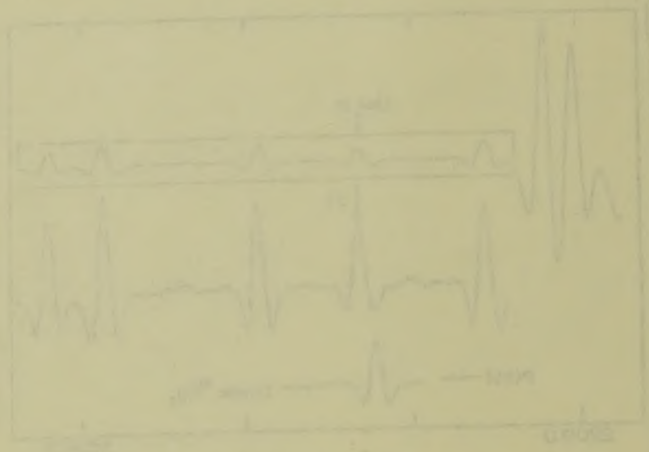
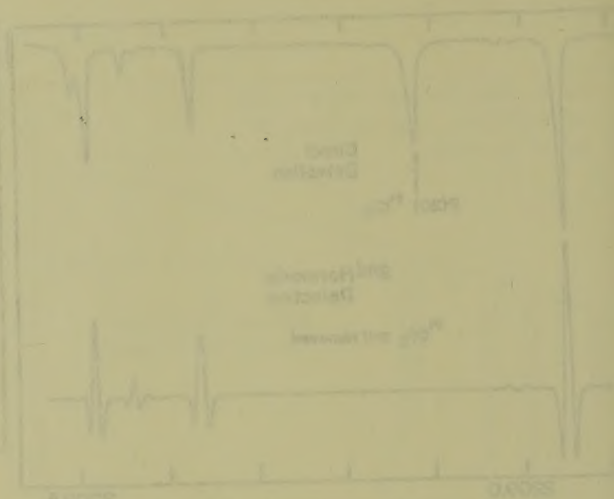




APPENDIX 7-1

A MULTIPOLLUTANT SAMPLER FOR INDOOR AND OUTDOOR AMBIENT AIR

L. D. Pengelly, A. T. Kerigan, C. H. Goldsmith, W. Furlong, W. Spurgeon, S. Toplack. Urban Air Environment Group, Department of Medicine, McMaster University, Hamilton, Ontario, Canada.

(Supported by Canada: Health and Welfare, and United Nations Environmental Programme/W.H.O.)

Binder et al have described a portable multi-pollutant sampler for particulates, SO_2 and NO_2. The Gage Research Institute has developed, built and operated multi-pollutant personal samplers. We have modified these designs to produce a stationary instrument capable of 24-hour indoor and outdoor automatic sampling. The instrument was specifically designed to address our present survey requirements. However, with minor modifications, the design can be adapted to meet a wide variety of sampling needs.

INSTRUMENT DESIGN AND CONSTRUCTION

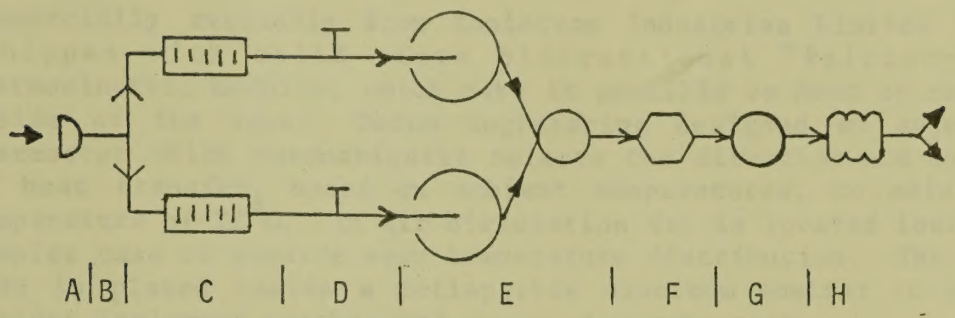
The instrument design was based on a combination of factors. We needed a low-cost unit capable of measuring ambient levels of particulate, NO_2 and SO_2 in school classrooms and residential living areas where service access, noise, aesthetics, safety and security are major considerations. In addition to being reliable and robust, the unit had to be easily relocated every three weeks and readily serviced in the field.

Construction of the instruments followed a modular format which had a number of advantages. Initially the modules could be mass produced, speeding assembly time and further ensuring comparabitity of the instruments. In addition, the modules are inter-changeable between instruments and permit replacement of major components in the field (without removing the entire sampler from the site) resulting in decreased down time, and hence, increased sample frequency. Construction experience proved invaluable training for service technicians. The following is a list of modules (bracketed letters refer to Figure 1):

1. Filter and support cassette (A);
2. Sample probe (B);
3. Manifold, flowmeters and housing (C);
4. Needle valves and support bracket (D);
5. Absorbing impingers and moisture trap in sample cartridge (E);
6. Electrical control and pump panel (F);
7. Temperature control panel;
8. Insulated case, wiring harness, moisture trap (G) and activated charcoal filter (H);
9. Collapsible aluminum weather shelter (outdoor instrument only).

FIGURE 1

MULTI-POLLUTANT SAMPLER SCHEMATIC

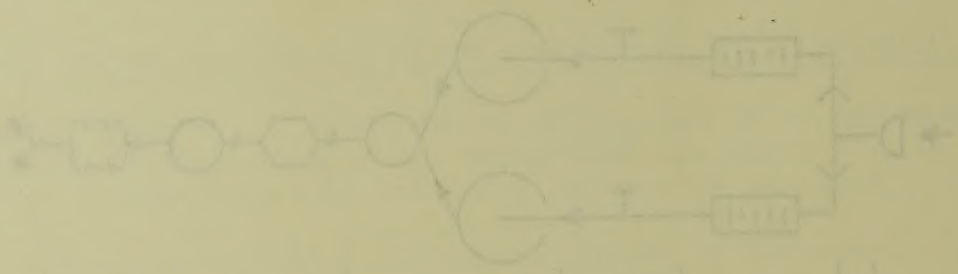


The entire sample train is constructed of chemically inert glass, teflon and machined 316 stainless steel. Sample air is drawn through a Millipore teflon filter (pore size, 1.0 um) mounted on a stainless steel support screen, before passing through a manifold which divides the air sample into two discrete sample streams. Flowmeters, visible from the exterior, continuously indicate the flow rates of each sample air stream. The streams pass through needle valves, bubble through impingers loaded with pollutant-specific absorbing solutions before being recombined in the cartridge moisture trap immediately upstream of the pump inlet. The impingers and moisture trap are supported in a metal case which is exchanged after each sample, and which is used to protect the solutions while in transit to the lab for analysis.

Flow rates are set at 500 ml per minute per impinger, or one litre per minute for particulate collection. These flow rates represent a compromise in order to obtain sufficient sample air required for accurate readings, while minimizing re-entrainment of air at indoor locations. Air flow regulation is achieved using two levels of control. First, the positive displacement pump is driven by a brushless D. C. motor equipped with an electronic phase-lock loop circuit (Datum Engineering Ltd., Burlington, Ontario) which maintains a constant motor speed referenced to an adjustable oscillator. The second level of control consists of in-line needle valves which allow the servicing technician to balance the flow rates through the impingers.

Sample air exhausted from the pump passes through a second moisture trap, and finally an activated charcoal filter before being returned to the ambient air. The double traps provide sufficient volume to ensure that absorbing solutions do not escape the sample case, as they present a potential hazard. The activated charcoal filter absorbs large molecular weight substances, such as phenols, which are released by the absorbing solutions and are the source of unpleasant odours.

The electrical systems, operating off a 110v 60hz line, provide sampling and temperature control. A seven-day programmable timer is incorporated to allow the sampler to be switched on and off while unattended. An elapsed timer provides an accurate record of sample duration. The temperature-controlled instrument case ensures a stable temperature ($+2^{\circ}C$) for the sample solutions with an ambient temperature range of -30° to $40^{\circ}C$. The case is



commercially available from Koolatron Industries Limited and is equipped with solid state bidirectional "Peltier-type" thermoelectric modules, which make it possible to heat or cool the inside of the case. Datum Engineering designed an adjustable thermostat which automatically selects the direction and duration of heat transfer, based on ambient temperatures, to maintain a temperature of 22°C. An air circulation fan is located inside the sampler case to provide even temperature distribution. The entire case is placed inside a collapsible aluminum shelter to protect against inclement weather and assure a secure site.

CALIBRATION AND VALIDATION

Chamber studies have been conducted to compare the sampler results to similar sampling devices and commercially available air quality monitors. Periodic chamber calibrations are performed in order to verify the gaseous pollutant readings obtained. Initial calibrations indicate the chemical methods used in our samplers correlate very well with commercially available monitors.

Three samplers are dedicated to a permanent Air Monitoring Station maintained by the Ontario Ministry of the Environment (M.O.E.). Particulate (T.S.P., COH, dustfall), SO_2 and NO_2 levels are recorded continuously at this site by the M.O.E. and our group will maintain concurrent P.S.D. sampling. During the course of the field survey, standard Total Suspended Particulate (T.S.P.) and Particle Size Distribution (P.S.D.) instruments are operated in relatively close proximity to the outdoor samplers to permit comparison of particulate results.

The sampling methods for both NO_2 and SO_2 are designated U.S. Environmental Protection Agency reference methods applicable to 24-hour field sampling. A brief summary of these methods is presented in the following table.

REFERENCE METHODS

	NO_2	SO_2
REFERENCE METHOD	TGS - ANSA	Pararosaniline (modified West-Gaeke)
ANALYTICAL TYPE	- colorimetric	- colorimetric
MIDGET IMPINGER TYPE	drawn glass orifice	fritted glass bubbler
COLLECTION EFFICIENCY	approx. 93% (20-750 ug/m^3)	>98% (above 25 ug/m^3)
SOLUTION STABILITY	stable for 3 weeks after exposure	stable for 30 days after exposure
INTERFERENCES	none at NO_2 concentration of 100 $\mu g/m^3$ (ammonia, CO, formaldehyde, NO_x, phenol, O_3, SO_2)	minimized or eliminated (NO_x, O_3, trace metals, ammonium, sulphides, aldehydes)

SURVEY DESIGN

The present project was developed to determine ambient indoor and outdoor levels of particulate, SO_2 and NO_2 in conjunction with a major respiratory health study of school children in the City of Hamilton. We expect to establish relationships between the indoor and outdoor environments and predict exposure levels based on population activity profiles. At any one time, we operate ten indoor and ten outdoor samplers in the network, plus the three "reference" samplers at the M.O.E. location.

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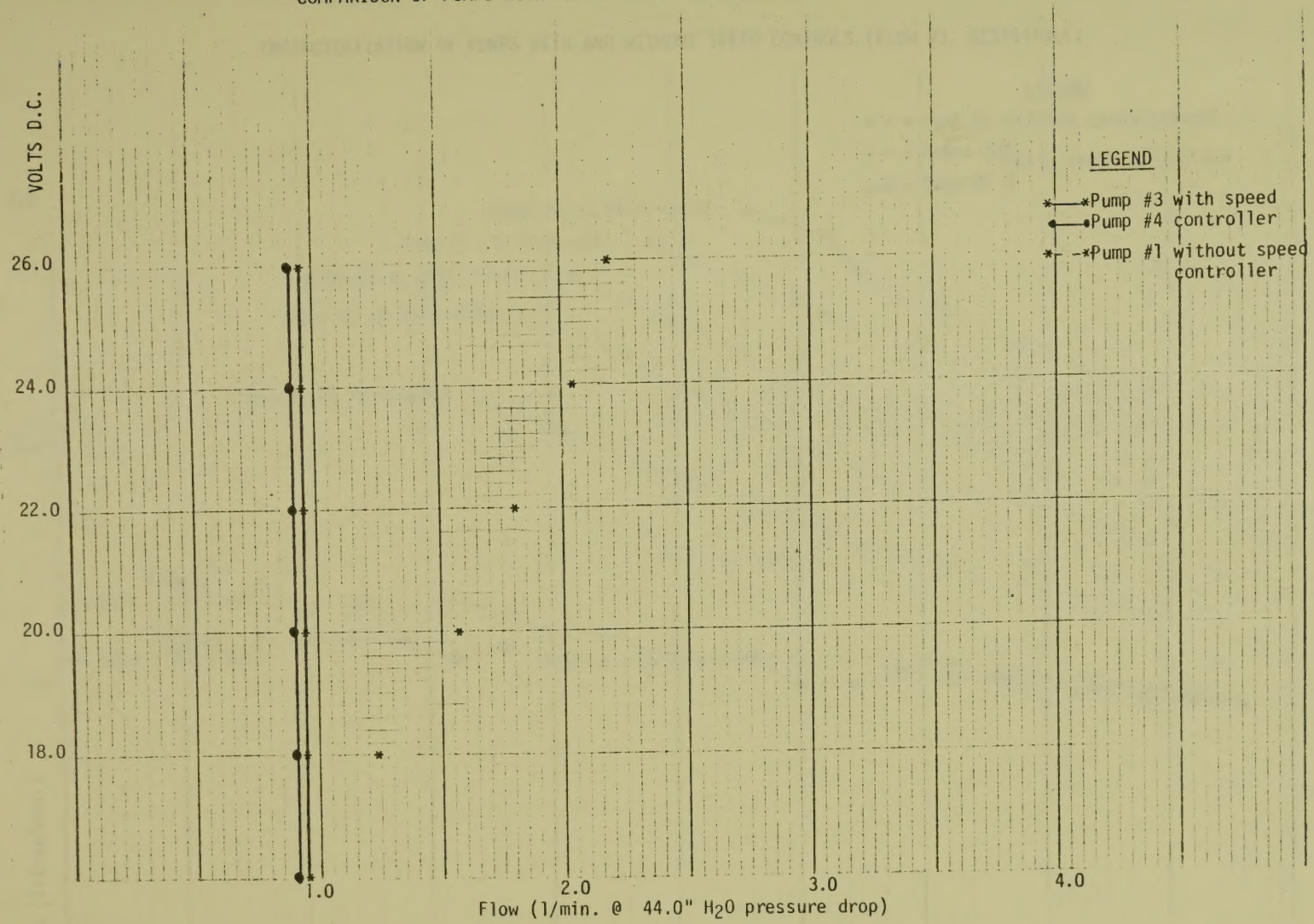
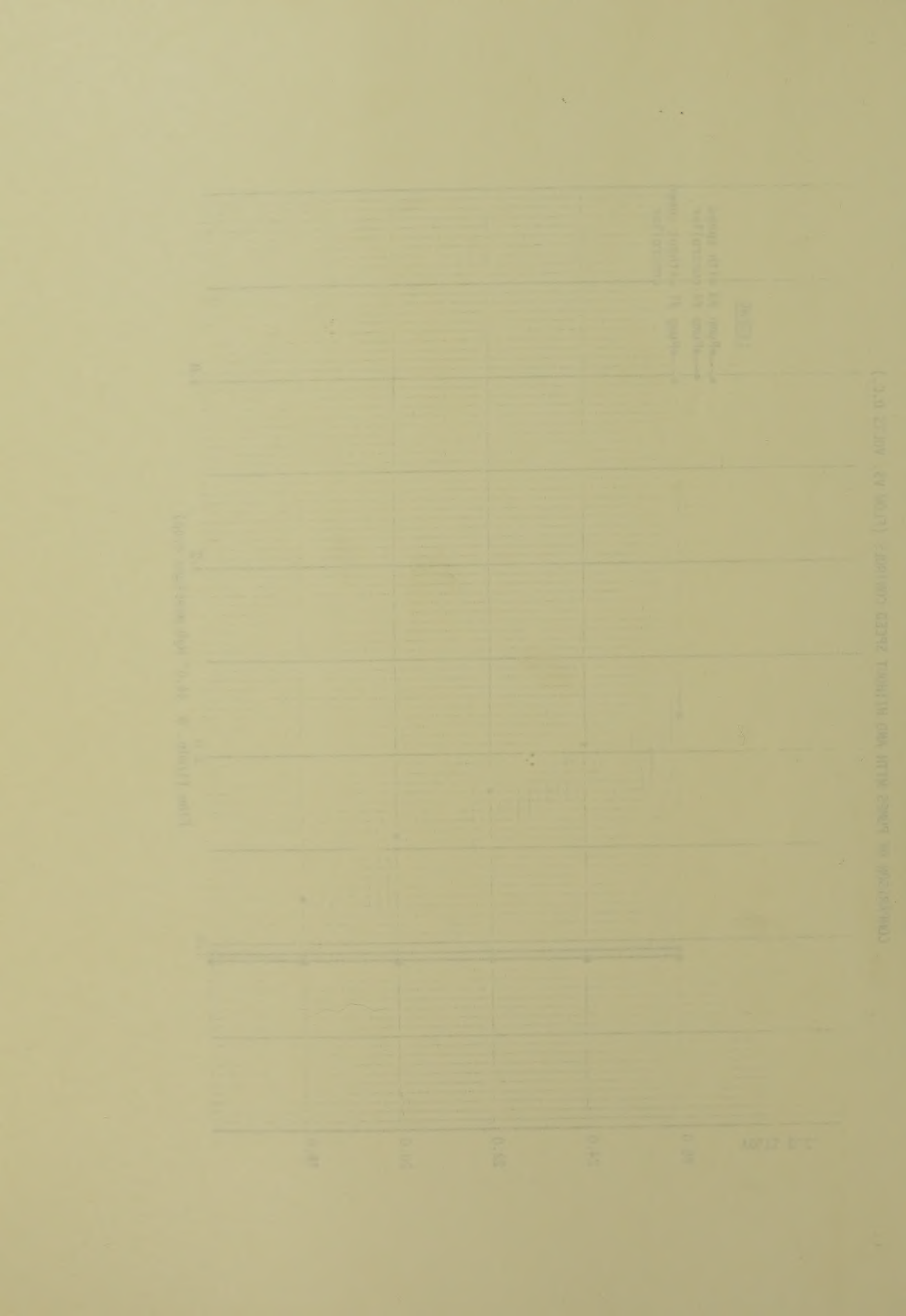
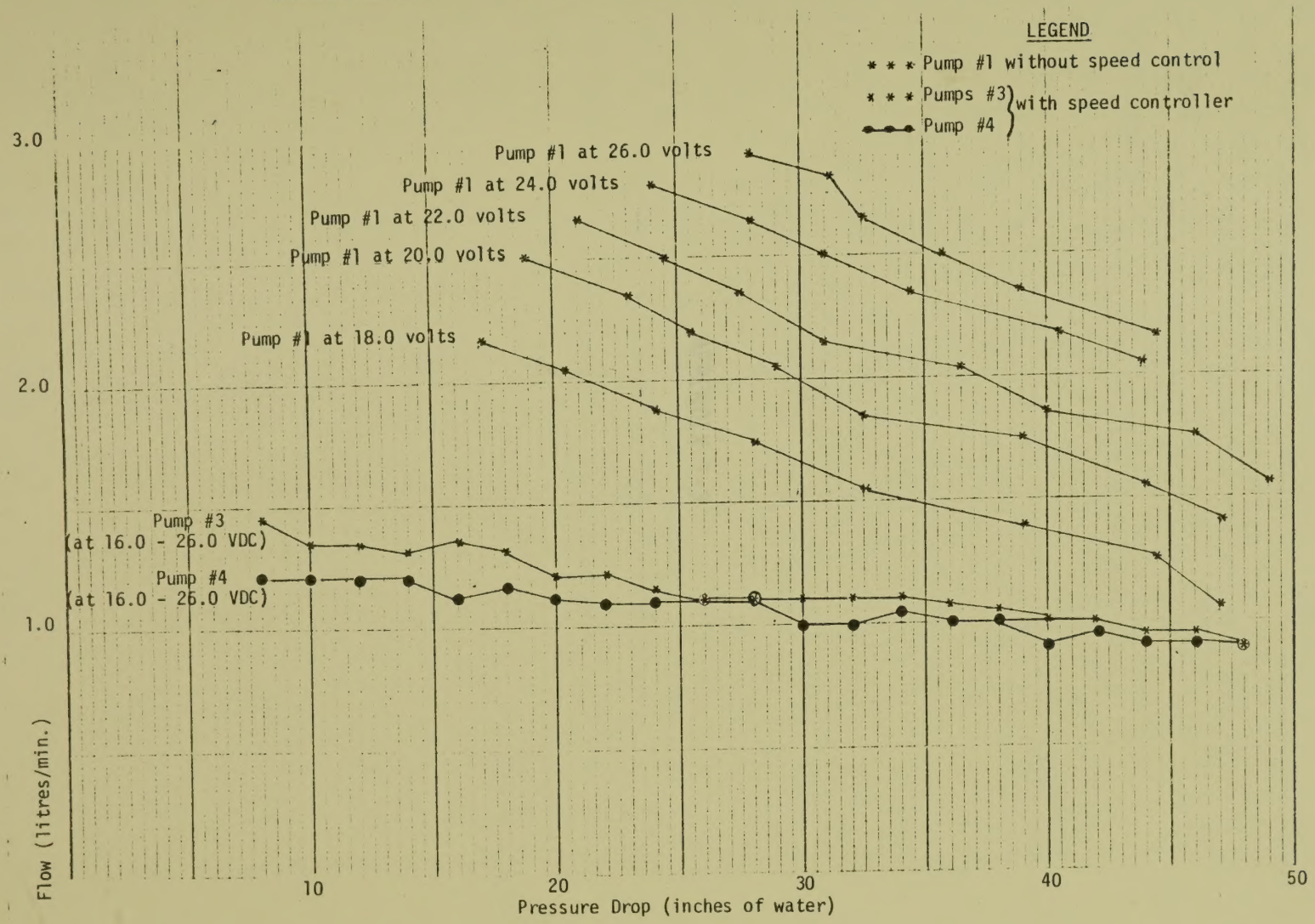
APPENDIX 7-2

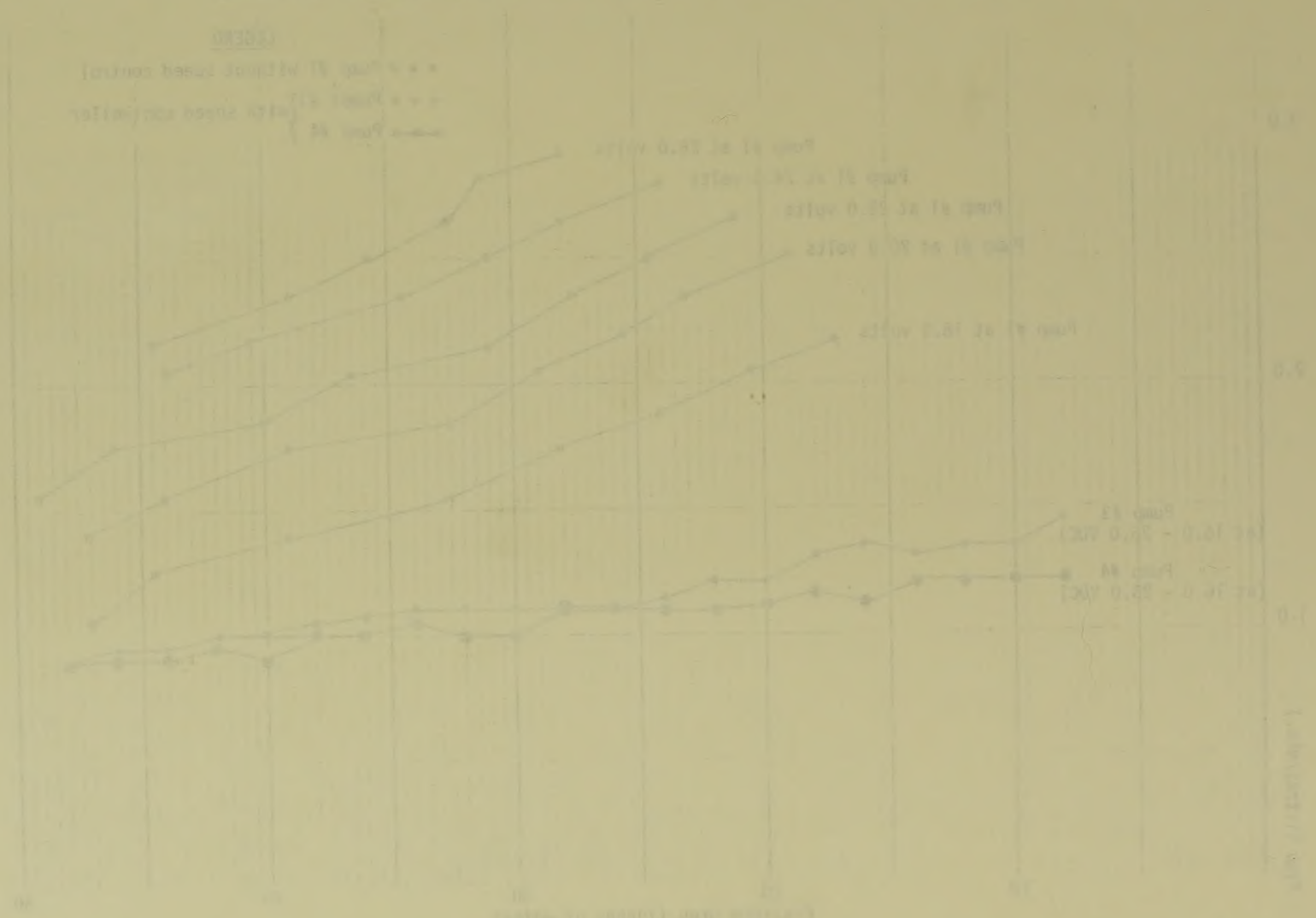
COMPARISON OF PUMPS WITH AND WITHOUT SPEED CONTROLS (FLOW VS. VOLTS D.C.)





CHARACTERIZATION OF PUMPS WITH AND WITHOUT SPEED CONTROLS (FLOW VS. RESISTANCE)





APPENDIX 7-3

I/O RESIDENTIAL DESCRIPTION FORM

ITE # _____ INDOOR , _____ OUTDOOR

ANDLORD _____ TELEPHONE # HOME _____

DDRESS _____ WORK _____

ITE VISIT DATE _____; BY _____

NSTALLATION DATE & TIME _____

NDOOR SITE: LOCATION _____

INSTRUMENT # _____

OUTLET	STATUS

UTDOOR SITE: LOCATION _____

INSTRUMENT # _____

OUTLET	STATUS

QUIPMENT REQUIRED

I/O SCHOOL SITE DESCRIPTION FORM

TE OF VISIT: _____ BY: _____

HOOL: _____ ADDRESS: _____

INCIPAL: _____

ACHER: _____

RETAKER: _____

ASSROOM # _____

T UP DATE & TIME: _____

ASSROOM LOCATION (sketch) INST. # _____

OUTLET	STATUS

UTDOOR LOCATION (sketch) INST. # _____

OUTLET	STATUS

oor plan obtained from school - YES _____ or NO _____

etch or notes on reverse - YES _____ or NO _____

APPENDIX 7-4

DATE:

COMMERCIAL BUILDING SURVEY

BUILDING NAME: SUBJECT NUMBER

ADDRESS:

I CONSTRUCTION:

1. WHAT YEAR WAS THE BUILDING BUILT?
2. HOW MANY FLOORS IN THE BUILDING?
3. WHAT FLOOR IS BEING MONITORED?
4. WHAT IS THE SQUARE FOOTAGE OF THIS FLOOR? (approx.)
5. WHAT TYPE OF SIDING IS ON THE BUILDING? 1 - aluminium
   2 - wood
   3 - brick
   4 - glass
6. WHAT TYPE OF FRAMEWORK IS IN THE EXTERIOR WALLS? 1 - cement
   2 - wood
   3 - steel
7. WHAT TYPE OF FINISH IS ON THE WALLS? 1 - mainly paint
   2 - mainly wallpaper
   3 - half & half
8. WHAT TYPE OF FLOORS ARE IN THE BUILDING? 1 - hard
   2 - soft
   3 - half & half
9. IS THERE AN UNDERGROUND GARAGE IN THE BUILDING? 1 - no 2 - yes
10. BRIEFLY DESCRIBE THE BUILDING. (i.e. school, factory, office, store)

II DOORS:

1. HOW MANY ENTRANCES/EXITS TO THE OUTSIDE ARE THERE ON THE MONITORED FLOOR?
2. HOW MANY OF THESE DOORS HAVE WEATHER STRIPPING?
3. HOW MANY OF THESE DOORS ARE GENERALLY OPEN DURING THE DAY?

III WINDOWS:

1. HOW MANY WINDOWS ARE THERE ON THE MONITORED FLOOR?
2. HOW MANY OF THESE WINDOWS HAVE STORMS OR ARE DOUBLE PANED?
3. HOW MANY OF THESE WINDOWS ARE GENERALLY OPEN DURING THE DAY?

IV HEATING:

1. WHAT TYPE OF FUEL IS USED TO HEAT THE BUILDING? 1 - oil
   2 - gas
   3 - electric
2. WHAT TYPE OF HEATING SYSTEM IS IN THE BUILDING? 1 - forced air
   2 - radiators
   3 - gravity
3. IS THERE A HUMIDIFIER ON THE MONITORED FLOOR? 1 - no 2 - yes

   IF 'YES', IS IT 1 - on the furnace
   2 - a separate unit
   3 - both

V VENTILATION:

1. IS THERE AIR CONDITIONING ON THE MONITORED FLOOR? 1 - no 2 - yes

   IF 'YES', IS IT 1 - central
   2 - window

   IS THE AIR EXHAUSTED OUTSIDE? 1 - no 2 - yes
2. IS THERE AN ELECTRONIC AIR CLEANER ON THE MONITORED FLOOR? 1 - no 2 - yes
3. ARE THERE WINDOW FANS ON THE MONITORED FLOOR? 1 - no 2 - yes

DATE:

BUILDING NAME:

ADDRESS:

SUBJECT NUMBER

VI GENERAL:

1. WHAT IS THE GENERAL LOCATION OF THE BUILDING? 1 - residential
   2 - commercial
   3 - industrial
   4 - rural
2. WHAT IS THE VOLUME OF TRAFFIC IN THE AREA? 1 - high
   2 - average
   3 - low
3. HOW MANY PEOPLE ARE THERE ON THE MONITORED FLOOR?
4. HOW MANY SMOKERS ARE THERE ON THE MONITORED FLOOR?
5. ARE THERE MANY TREES IN THE AREA? 1 - no 2 - yes
6. ARE THE TREES 1 - YOUNG? 2 - MATURE? 3 - BOTH?
7. ARE THERE NEARBY SOURCES OF AIR POLLUTION? 1 - no 2 - yes
   IF 'YES', PLEASE DESCRIBE. (narrative)

APPENDIX 7-5

RESIDENTIAL SURVEY

DATE: | | | | | | |

SUBJECT NAME: _____

ADDRESS: _____

TELEPHONE # _____ WORK # _____

SUBJECT NUMBER | | | | |

I CONSTRUCTION:

1. DO YOU LIVE IN A 1 - house? 2 - apartment?

   IF APARTMENT - WHAT FLOOR DO YOU LIVE ON?

   ARE YOU CLOSE TO AN EXIT? 1 - no 2 - yes

   IF HOUSE - IS IT 1 - single dwelling?
   2 - semi-detached?
   3 - row housing?

   DO YOU HAVE A FIREPLACE? 1 - no 2 - yes

   IF "YES", HOW MANY?

   HOW MANY CHIMNEYS DO YOU HAVE?

   DO YOU HAVE A BASEMENT? 1 - no 2 - yes

   IF "YES", IS IT 1 - finished?
   2 - unfinished?

2. WHAT YEAR WAS YOUR HOME BUILT?

3. HOW MANY FLOORS DOES YOUR HOME HAVE?

   1 - 1
   2 - 1 1/2
   3 - 2
   4 - 2 1/2
   5 - 3
   6 - split level

4. WHAT IS THE BASIC SHAPE OF YOUR HOME?

   1 - 2 - 3 - 4 - 5 -

5. WHAT IS THE SQUARE FOOTAGE OF YOUR HOME? (approx.)

6. HOW MANY FINISHED ROOMS ARE THERE IN YOUR HOME?

7. WHAT TYPE OF SIDING DO YOU HAVE ON YOUR HOME?

   1 - aluminium
   2 - wood
   3 - brick
   4 - other (specify) _____

8. WHAT TYPE OF FRAMEWORK DO YOU HAVE IN THE EXTERIOR WALLS?

   1 - cement
   2 - wood
   3 - steel
   4 - double brick

9. HOW MUCH OF THE EXTERIOR WALLS ARE INSULATED? 1 - most
   2 - half
   3 - none

10. HOW MUCH INSULATION IS IN THE ATTIC? 1 - under 4"
    2 - 4-8"
    3 - none

11. WHAT TYPE OF INSULATION IS PRIMARILY USED?

    1 - glass fibre
    2 - urea formaldehyde
    3 - cellulose
    4 - other (specify)

DATE: ☐☐-☐☐-☐☐

SUBJECT NUMBER ☐☐☐☐

12. WHAT TYPE OF FLOOR COVERING DO YOU HAVE? ☐

1 - hard
2 - soft
3 - half + half

13. WHAT TYPE OF FINISH DO YOU HAVE ON YOUR WALLS? ☐

1 - mainly paint
2 - mainly wallpaper
3 - half + half

14. WHAT TYPE OF FURNITURE DO YOU HAVE? 1 - mainly soft ☐
2 - mainly hard
3 - half + half

15. DO YOU HAVE A GARAGE? 1 - no 2 - yes ☐

IF "YES", IS IT ATTACHED? 1 - no 2 - yes ☐

IF "YES", HOW MANY ROOMS ABOVE THE GARAGE DO YOU HAVE? ☐☐

II DOORS:

1. HOW MANY ENTRANCES/EXITS SEPARATE THE LIVING AREA OF YOUR HOME FROM THE OUTSIDE? ☐

2. HOW MANY OF THESE ENTRANCES/EXITS HAVE STORM DOORS? ☐

3. HOW MANY OF THESE ENTRANCES/EXITS HAVE WEATHER STRIPPING? ☐

4. HOW MANY OF THE MAIN DOORS ARE GENERALLY OPEN DURING THE DAY? ☐

III WINDOWS:

1. HOW MANY WINDOWS SEPARATE THE LIVING AREA OF YOUR HOME FROM THE OUTSIDE? ☐

2. HOW MANY OF THESE WINDOWS HAVE STORMS OR ARE DOUBLE PANED? ☐

3. HOW MANY OF THESE WINDOWS RATTLE OR HAVE NOTICABLE DRAFTS? ☐

4. HOW MANY ARE GENERALLY OPEN DURING THE DAY? ☐

5. HOW MANY ARE GENERALLY OPEN DURING THE NIGHT? ☐

DATE: | | | | | |

SUBJECT NUMBER

IV HEATING:

1. WHAT TYPE OF FUEL DO YOU PRIMARILY USE TO HEAT YOUR HOME? ☐

   1 - oil
   2 - gas
   3 - electric
   4 - wood
   5 - solar

2. WHAT TYPE OF HEATING SYSTEM DO YOU HAVE IN YOUR HOME? ☐

   1 - forced air
   2 - radiators
   3 - gravity

3. DO YOU HAVE AUXILARY SPACE HEATER IN YOUR HOME? 1 - no 2 - yes ☐

   IF "YES", IS IT 1 - gas 2 - oil 3 - other (specify)_____ ☐

4. DO YOU HAVE A HUMIDIFIER IN YOUR HOME? 1 - no 2 - yes ☐

   IF "YES", IS IT 1 - on your furnace?
   2 - separate unit?
   3 - both? ☐

5. WHAT TYPE OF STOVE DO YOU HAVE IN YOUR KITCHEN? 1 - gas
   2 - electric
   3 - wood ☐

6. DO YOU HAVE A GAS OPERATED HOT WATER TANK? 1 - no 2 - yes ☐

V VENTILATION:

1. DO YOU HAVE AIR CONDITIONING IN YOUR HOME? 1 - no 2 - yes ☐

   IF "YES", IS IT 1 - central? 2 - window? ☐

   IS THE AIR EXHAUSTED OUTSIDE? 1 - no 2 - yes ☐

2. DO YOU HAVE AN ELECTRIC AIR CLEANER IN YOUR HOME? 1 - no 2 -yes ☐

3. DO YOU HAVE A VENTILATION SYSTEM (exhaust fan) OVER YOUR STOVE? 1 - no 2 - yes ☐

   IF "YES", DOES IT EXHAUST OUTSIDE? 1 - no 2 - yes ☐

4. DO YOU USE A WINDOW FAN? 1 - no 2 - yes ☐

5. DO YOU HAVE ANY VENTILATION IN THE BATHROOM? 1 - no 2 - yes ☐

DATE: ☐☐☐☐☐☐

SUBJECT NUMBER ☐☐☐☐

6. DO YOU HAVE ANY VENTILATION IN THE LAUNDRY ROOM?
   1 - no 2 - yes ☐

7. DO YOU HAVE AN ATTIC? 1 - no 2 - yes ☐

   IF "YES", DO YOU HAVE A VENTILATION FAN IN THE ATTIC?
   1 - no 2 - yes ☐

VI GENERAL:

1. WHAT IS THE GENERAL LOCATION OF YOUR HOME? 1 - residential
   2 - commercial
   3 - industrial
   4 - rural ☐

2. WHAT IS THE VOLUME OF TRAFFIC ON YOUR STREET? 1 - high
   2 - average
   3 - low ☐

3. DO YOU HAVE ANY PETS THAT CAUSE YOU TO OPEN AND CLOSE THE DOORS? 1 - no 2 - yes ☐

4. HOW MANY PEOPLE LIVE IN YOUR HOME? - ADULTS? ☐☐

   - CHILDREN? ☐☐

5. HOW MANY SMOKERS IN YOUR HOME? ☐☐

6. HOW WOULD YOU DESCRIBE YOUR HOME? 1 - airtight
   2 - normal
   3 - permiable ☐

7. ARE THERE MANY TREES IN YOUR NEIGHBORHOOD? 1 - no 2 - yes ☐

8. ARE THE TREES 1 - young? 2 - mature? 3 - both? ☐

9. HOW LONG HAVE YOU LIVED IN THIS RESIDENCE? ☐☐

10. ARE THERE ANY NEARBY SOURCES OF AIR POLLUTION?
    1 - no 2 - yes ☐

11. PLEASE DESCRIBE TYPE:
    1 - traffic heavy
    2 medium
    3 light ☐
    4 - heavy industry
    5 - light industry & commercial
    6 - other

12. DOES ANY MEMBER OF YOUR FAMILY SUFFER RESPIRATORY PROBLEMS?
    1 - no 2 - yes ☐
    Specify_____

PLEASE TURN OVER FOR COMMENTS.

APPENDIX 7-6

RESIDENTIAL SITE SUMMARY

SITE#	RESIDENT OR LANDLORD	RES.	GARAGE	HEAT FUEL	TYPE	STOVE	A/C	ADULTS	CHILD	SMOKE	I.D.#	SUMMER SAMPLE	WINTER SAMPLE
				SITE CHARACTERISTICS									
1A	LAFFERTY	H(1900)	G	G	F	E	-	2	2	1	73	YES	YES
3A	BASKIN	H(1852)	G+	O	R	E	W	2	-	1	1	PART	YES
5A	PENGELLY	H(1927)	G	G	R	E	C	2	3	-	75	NO	YES
1B	PATTISON	H(1925)	G	G	F	E	-	2	2	-	13	YES	NO
3B	WHITFIELD	A(1940)	G+	E	R	E	-	1	-	1	58	YES	YES
5B	WALES	H(1910)	-	G	F	G	-	2	1	-	39	YES	YES
7B	PHILLIPS	H(1940)	G	G	F	E	W	2	1	-	38	PART	NO
1C	WILLOCK	H(1940)	G	G	F	G	-	1	-	-	15	YES	YES
3C	LAW	H(1890)	G+	G	F	E	-	4	3	-	46	YES	YES
5C	SPURGEON	H ?	-	G	F	G	-	3	-	2	N/A	NO	YES
9C	KOHNE	A ?	U.G.	G	R	E	-	2	1	1	27	YES	YES
1D	CORRIGAN	H(1947)	G+	W	G	E	-	2	-	-	69	YES	YES
3D	DROTAR	A(1975)	U.G.	E	R	E	-	2	2	-	68	YES	YES
5D	ROBERTSON	H(1970)	-	G	F	E	-	2	2	2	51	YES	NO?
7D	CORRIN	H(1972)	?	G	F	E	W	2	1	1	35	NO	?

. . .

SITE#		RESIDENT OR LANDLORD		RES.	GARAGE	HEAT FUEL	TYPE	STOVE	A/C	ADULTS	CHILD	SMOKE	I.D.#	SUMMER SAMPLE	WINTER SAMPLE
1E		TOPLACK		H(1925)	-	G	F	E	-	2	2	-	17	YES	YES
5E		MEMZIES		H(1960)	G+	G	F	E	C	2	2	-	32	YES	YES
7E		CAIRNS		H(1971)	-	G	F	E	-	2	2	1	36	YES	YES
9E		BOOKER		H(1940)	-	G	F	E	-	2	-	1	67	NO	NO
1F		INMAN		H(1967)	G+	G	F	E	C	5	-	-	10	YES	YES
3F		JONES		H(1960)	-	G	F	E	W	2	2	1	70	YES	YES
5F		HUBERT		H(1973)	-	G	F	E	W	2	2	1	25	YES	YES
9F		GRIFFITHS		H(1967)	-	G	F	E	C	2	1	-	74	YES	YES

RESIDENTIAL SITE SUMMARY

LEGEND

Res. (Residence Type)

- H: Single-family dwelling
- A: Apartment
- (year): Year building was constructed

Garage

- G: Ground level
- G+: Above grade
- U.G.: Under ground

Heat Fuel

- G: Gas (natural or propane)
- O: Oil
- E: Electric heat
- W: Wood

Type (of heating circulation system)

- F: Forced air
- R: Radiant heat (radiators, etc.)
- G: Gravity

Stove

- E: Electrical
- G: Gas

A/C (Air Conditioning)

- W: Window unit(s)
- C: Central system

Adults

Number normally resident

Children

Number normally resident

Smoke

Number of smokers normally resident

I.D. #

Residential description questionnaire number

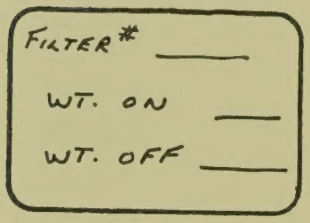
SUMMER SAMPLE -
- YES - Sampling Complete
- NO - Sampling Not Attempted
- PART - Sampling Partially Completed

WINTER SAMPLE -
- YES - Site Suitable
- NO - Unable to use site

APPENDICES 7-7 and 7-8

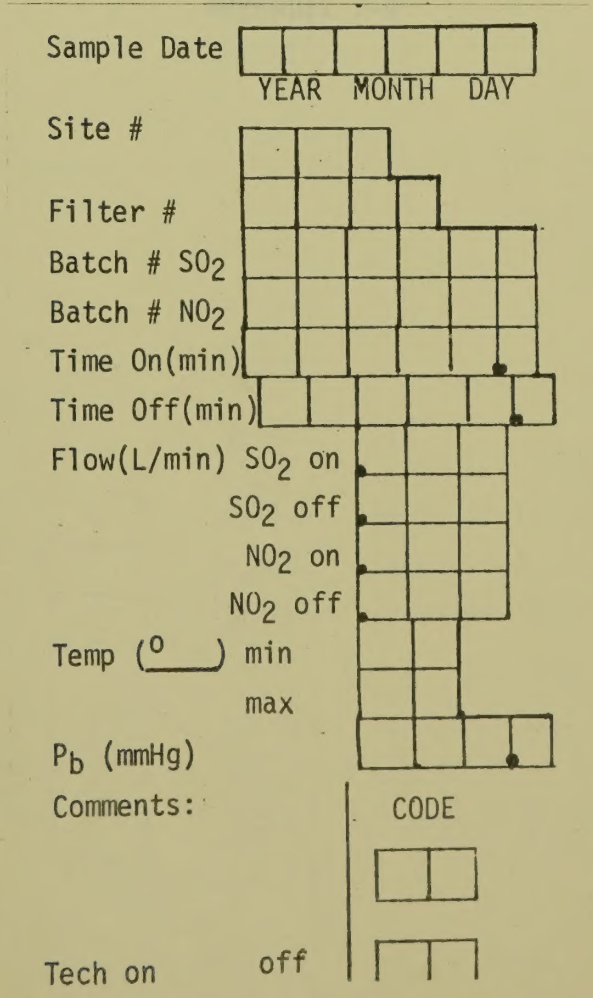
APPENDIX 7-7

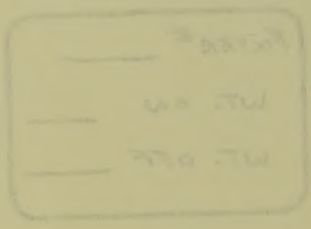
FILTER DATA LABEL



APPENDIX 7-8

FIELD DATA FORM

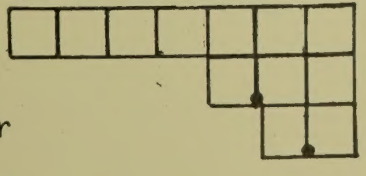


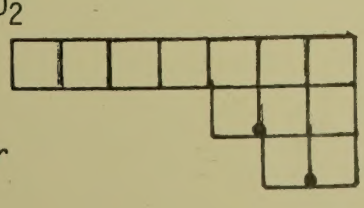


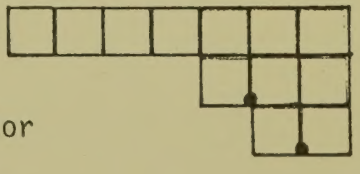
APPENDIX 7-9

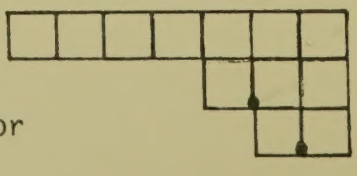
I/O CODING FORM

INDOOR		OUTDOOR	
	1-6		1-6
	7-9		7-9
	10-13		10-13
	14-19		14-19
Field Note	20-25	Field Note	20-25
	26-31		26-31
	32-37		32-37
	38-40		38-40
	41-43		41-43
	44-46		44-46
	47-49		47-49
	50-51		50-52
	52-53		
	54-57		53-56
	58-59		57-58
	60-61		59-60
Filter Data		Filter Data	
	62-65		61-44
	66-70		65-69
	71-75		70-74
NO_2		NO_2	
ysis Date	76-82	Analysis Date	75-81
e Abs	83-85	Sample Abs	82-84
ion Factor	86-87	Dilution Factor	85-86
SO_2		SO_2	
ysis Date	88-94	Analysis Date	87-93
e Abs	95-97	Sample Abs	94-96
ion Factor	98-99	Dilution Factor	97-98









APPENDIX 9-1

School Term Questionnaires

A - Administered on Tuesday to Friday (re weekdays)

B - Administered on Mondays (re weekends)

Administered in school to child by assistant pulmonary function technician.

I.D. [ ][ ][ ][ ][ ] (1–5)

ACTIVITY PROFILE - QUESTIONNAIRE A

(Administered on Tuesday - Friday)

CARD [ ] (6)

6

PRESENT SCHOOL [ ][ ] (7–8)

e would like to have an idea of how you spent the last 24 hours.
e would be pleased if you would answer the following questions.

(code actual time)

. What time did you leave home for school today? _____ [ ][ ][ ][ ] (9–12)

. Did you walk to school? 1) yes 2) no _____ [ ] (13)

he following questions all refer to what you did yesterday.

(code actual time)

. What time did you leave school yesterday? _____ [ ][ ][ ][ ] (14–17)

. Did you play outdoors before going home (after school) yesterday? _____

(If yes answer the following, otherwise, go to question #5)

(code in minutes)

4a) How long? _____ [ ][ ][ ] (18–20)

. Did you play outdoors after getting home yesterday? _____

(If yes answer the following, otherwise, go to question #6)

(code in minutes)

5a) How long? _____ [ ][ ][ ] (21–23)

. Did you stay at school or go home for lunch yesterday?
1) home ( ) 2) school ( ) [ ] (24)

(code in minutes)

. How much of your lunch break was spent outdoors? _____ [ ][ ][ ] (25–27)

8. Did you go outdoors during school time other than recess or lunch time? _____

(code in minutes)

8a) How long? _____

28 30

TO BE FILLED IN BY THE INTERVIEWER

(code actual time)

i) Time school starts _____

31 34

(code in minutes)

ii) Time spent for recess outdoors _____

35 37

(code in minutes)

iv) Length of lunch break _____

38 40

(code in minutes)

DATE OF INTERVIEW

41 44

I.D. [ ][ ][ ][ ][ ] (1–5)

CARD [ ] (6–7)

ACTIVITY PROFILE - QUESTIONNAIRE B

(Administered on Mondays)

PRESENT SCHOOL [ ][ ] (7–8)

would like an idea of how you spent this past weekend.
would be pleased if you would answer the following questions.

---

following question refers to what you did on Saturday.

How much time did you spend outdoors on Saturday?

a) before lunch - if no time, go to 1 b) - otherwise - [ ][ ][ ] (9–11) Code in Min.

was this - i) near home _____ [ ] (12)

ii) elsewhere _____

b) between lunch and supper - if no time, go to 1 c) - otherwise - [ ][ ][ ] (13–15) Code in Min.

was this - i) near home _____ [ ] (16)

ii) elsewhere _____

c) after supper [ ][ ][ ] (17–19) Code in Min.

was this - i) near home _____ [ ] (20)

ii) elsewhere _____

---

following question refers to what you did on Sunday.

How much time did you spend outdoors on Sunday?

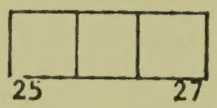
a) before lunch - if no time, go to 2 b) - otherwise - [ ][ ][ ] (21–23) Code in Min.

was this - i) near home _____ [ ] (24)

ii) elsewhere _____

Activity Profile - Questionnaire B

b) between lunch and supper - if no time, go to 2 c) - otherwise

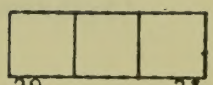


Code in Min.

was this i) near home _____

ii) elsewhere _____

c) after supper

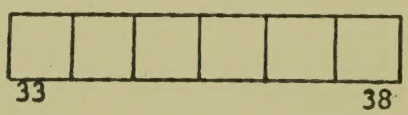


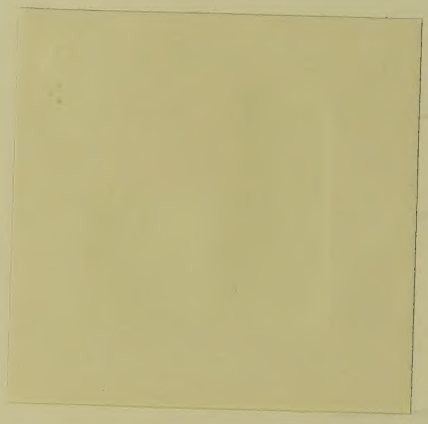
Code in Min.

was this i) near home _____

ii) elsewhere _____

DATE OF INTERVIEW





Summer Questionnaires

A - Administered on Tuesday to Friday (re weekdays)

B - Administered on Mondays (re weekends)

Administered by phone to parent by pulmonary function technician.

I.D. [ ][ ][ ][ ][ ] (1–5)

QUESTIONNAIRE A
(ADMINISTERED ON TUESDAY-FRIDAY)

CARD [1][0] (6–7)

What school is your child presently attending? _____ [ ][ ] (8–9) school no.

a) Is yourchild attending day camp this summer? _____ [ ][ ] (10–11) days

If yes, how much time will he be spending there? _____

Is it (i) near home

(ii) elsewhere in Hamilton and where

(iii) outside of Hamilton [ ] (12)

If no, go to 2B

b) If yourchild is not attending day camp, is he going some place else on a regular basis on weekdays? _____

If yes, is it (i) near home _____

(ii) elsewhere in Hamilton,

and where _____

(iii) outside of Hamilton _____ [ ] (13) code location no.

How much time per week will he be spending there? _____ [ ][ ] (14–15) hours per week

How much time is your child spending outside of Hamilton this summer? _____ [ ][ ] (16–17) days

Was your child in Hamilton yesterday? _____

If yes, continue questionnaire.

If no, do not ask any further questions.

ACTIVITY PROFILE - QUESTIONNAIRE A

How much time did your child spend outdoors yesterday?

a) before lunch - if no time, go to 5B

otherwise - was this (i) near home _____

(ii) elsewhere _____

18 code in min. 20

21

b) between lunch and supper - if no time, go to 5C - otherwise - was this - (i) near home _____

(ii) elsewhere _____

22 code in min. 24

25

c) after supper

was this - (i) near home _____

(ii) elsewhere _____

26 code in min. 28

29

DATE OF INTERVIEW

Day Month Year

30 35

I.D. [ ][ ][ ][ ][ ]
1 5

QUESTIONNAIRE B
(ADMINISTERED ON MONDAYS)

Card [1][1]
6 7

What school is your child presently attending? _____

[ ][ ]
8 9
school no.

a) Is your child attending day camp this summer? _____

If yes, how much time will he be spending there? _____

Is it (i) near home

(ii) elsewhere in Hamilton and where

(iii) outside of Hamilton

[ ][ ]
10 11
Days

[ ]
12

b) If your child is not attending day camp, is he going some place else on a regular basis on weekdays? _____

If yes, is it (i) near home _____

(ii) elsewhere in Hamilton and where _____

(iii) outside of Hamilton _____

How much time per week will he be spending there? _____

[ ]
13
code location no.

[ ][ ]
14 ~~14~~ 15
Hours per week

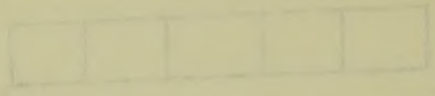
How much time is your child spending outside of Hamilton this summer? _____

[ ][ ]
16 days ~~16~~ 17

Was your child in Hamilton this past weekend? _____

If yes, continue questionnaire.

If no, do not ask any further questions.



ACTIVITY PROFILE-QUESTIONNAIRE B

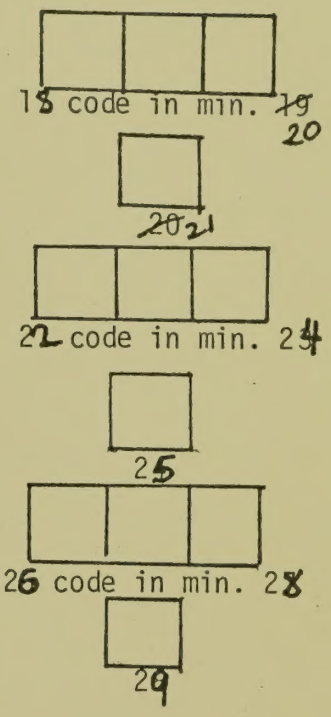
We would like an idea of how your child spent this past weekend.

How much time did your child spend outdoors on Saturday? _____

a) before lunch - if no time, go to 5B otherwise -
was this (i) near home _____
(ii) elsewhere _____

b) between lunch and supper if no time, go to 5C -
otherwise - was this (i) near home _____
(ii) elsewhere _____

c) after supper
was this - (i) near home
(ii) elsewhere

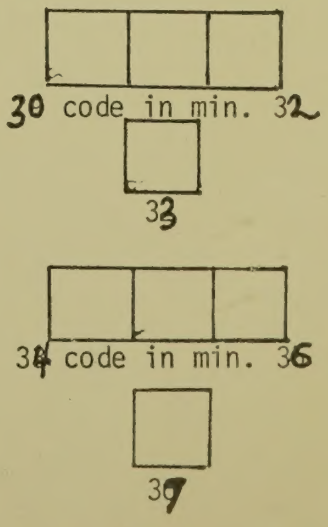


The following question refers to what your child did on Sunday.

How much time did your child spend outdoors on Sunday?

a) before lunch - if no time, go to 6B - otherwise -
was this (i) near home
(ii) elsewhere

b) between lunch and supper - if no time
go to 6C, otherwise - was this -
(i) near home
(ii) elsewhere

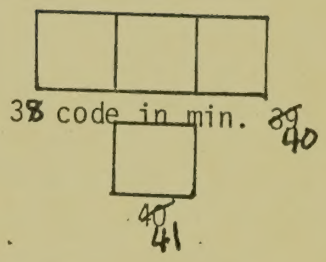


ACTIVITY PROFILE-QUESTIONNAIRE B

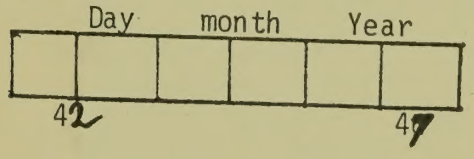
c) after supper

was this (i) near home

(ii) elsewhere



DATE OF INTERVIEW



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